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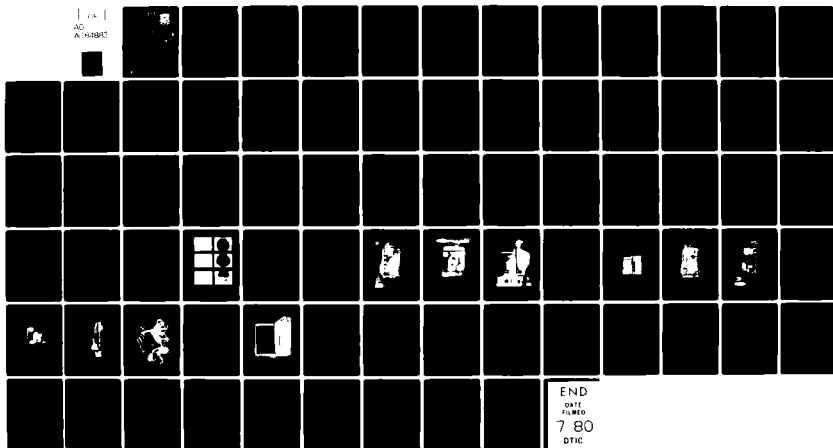
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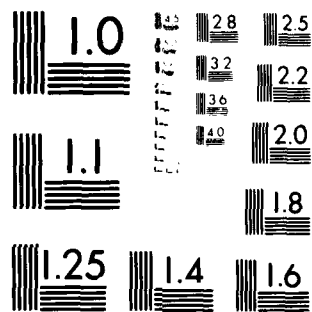
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PREFACE

This report was prepared by Spectronics, a Division of Honeywell Inc., Richardson, Texas under contract F33615-78-C-1490 and is the final report covering the period from August 1978 through September 1979. The principal persons at Spectronics were Mr. Ben Elmer and Mr. Gary Mangus while the contract monitor for the Air Force Avionics Laboratory was Mr. Melvin St. John. The work was accomplished under project 6096, Microelectronics Technology, task 41, Integrated Circuit Development. The integrated circuits which are the key components within the modules developed under this effort were developed earlier by Honeywell under contracts F33615-76-C-1275 and F33615-76-C-1280. Details of these related efforts are reported in AFAL-TR-78-107, "Fiber Optics Transmitter Integrated Circuit Development", ADA071437, and in AFAL-TR-78-185, "Fiber Optics Receiver Integrated Circuit Development", ADA064966.

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SECTION I

INTRODUCTION AND SUMMARY

Fiber optics has an ultimate goal of providing sophisticated signal transmission systems which use the high bandwidth and high interference rejection capabilities of fiber optic links. These transmission systems would be lightweight, small, economical, and immune to electro-magnetic interference (EMI).

This document constitutes the final technical report of a development program to design, fabricate, test, and deliver approximately 50 sets of transmitter and receiver modules for data transmission via fiber optic bundles at data rates of 10 KB/s to 10 MB/s. As a result of the development program, a set of low cost fiber optic modules are readily available that are optimized for producibility, wide use, high reliability, and EMI/EMP resistance.

This report documents the technical work performed in the development of the transmitter and receiver module set. In addition, information is included for the user. This report begins by describing the general functions and circuits of the modules. The transmitter and the receiver module designs are treated individually and application information is included for both. The thermal model of the module is developed in the next section. The module assembly steps are also discussed. Finally, the complete testing, burn-in, and results are presented.

RECOMMENDATIONS

There are two major areas that can be addressed to improve the low cost fiber optic modules.

- Cost Reduction
- Yield Improvement

Cost Reduction

The transmitter and receiver module costs are relatively low, as shown in Table 1. At the present time transmitter module unit cost is about \$183 and the receiver module unit cost is about \$210 in production quantities of 100. A manufacturing technology program to study the use of automation as a means of reducing piece part costs, along with studies of batch tooling and

Table 1
Low Cost Fiber Optic Modules

	<u>XMT</u>	<u>REC</u>
LCC, I.C.	\$ 30.00	\$ 30.00
LED OR PIN DIODE	40.00	44.00
METAL COMPONENTS	10.70	10.53
(a) End Plate	1.45	1.45
(b) Retaining Plate	.48	.48
(c) Housing	.50	.50
(d) Optical Connector	6.35	6.35
(e) Nut	.53	.53
(f) Lockwasher	.53	.53
(g) 3 screws	.69	.69
(h) Heatsink	.17	--
CAPACITORS	.90	2.95
(a) .1 μ f	.28	.56
(b) .01 μ f		.18
(c) 1.0 μ f		1.59
(d) 4.7 μ f	.62	.62
SUBSTRATE	14.14	29.00
ASSEMBLY		
(a) Labor	7.74	7.74
(b) L.O.H. @189%	14.62	14.62
TESTING	<u>20.20</u>	<u>20.20</u>
SUBTOTAL	138.30	159.04
G&A @28%	<u>24.89</u>	<u>28.63</u>
SUBTOTAL	163.19	187.67
PROFIT @12%	<u>19.58</u>	<u>22.52</u>
TOTAL	\$ 182.77	\$ 210.19

manufacturing aids should be performed with the goal of achieving a production cost goal of approximately \$50.

Yield Improvement

The photodiode components had a serious yield problem when subjected to the acceleration test of 15,000 G's in the Y² direction. A development program should be performed to develop a photodiode component to meet the military specifications.

Other module yield improvement areas exist but are not as evident as the photodiode yield problem. These less evident yield areas would be expected to improve in the normal production environment.

SECTION II

TRANSMITTER CIRCUIT DESCRIPTION

Figure 1 is a block diagram and a listing of the salient characteristics of the Fiber Optic Transmitter Module.

The primary function of the transmitter module is to convert a digital TTL signal into an emitted light signal. This is performed by switching "on or off" a 100mA current source connected in series with a light emitting diode (LED). The input of the transmitter module is equivalent to a standard 5400-type TTL AND gate. Input must be high (TTL "1") to switch on the 100 mA current source through the LED that produces the light output. Either input being low (TTL "0") switches the 100mA current source off and, thus, switches the LED light output off.

CHARACTERISTICS:

- 1.) LED Driven by 100mA constant current source
- 2.) DC to 10 M bits/sec operation
- 3.) -54°C to 95°C operation
- 4.) 50 μ A pre-bias current source for LED
- 5.) 750 μ Watts minimum radiant power output
(NA = .42, .045 inch dia. optical aperture)

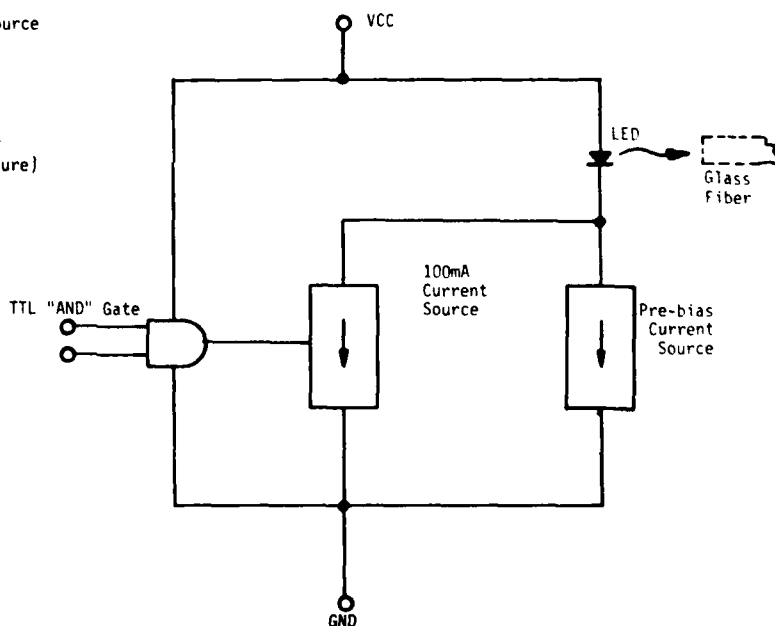


Figure 1.
Fiber Optic Transmitter Module
Block Diagram

CONSTANT CURRENT CAPABILITY

The constant current source provided in the transmitter module is important because LED life expectancy is increased by holding the current constant. If only a transistor is used to drive the LED, the LED current can change by a factor of 2 to 4 over a temperature range of -55 to 125°C.⁽¹⁾ The power supply variation on a 5V supply of only $\pm 10\%$ can produce a 25% change in the 100mA LED drive current. The constant current source ensures that the LED current is constant with variations in supply voltage and operating temperature. Any increase in LED current can produce excess power dissipation and decrease the life of the LED.

PRE-BIAS CURRENT

The pre-bias current source ensures that when the 100mA current source is switched off, there is a 50 μ A current pulled through the LED. This small pre-bias current keeps the LED just below the turn-on point and enhances the turn-on speed of the LED.¹

RADIANT POWER OUTPUT (RPO)

The transmitter module provides 750 μ Watts minimum of radiant power into a .045 inch diameter optical aperture with a numerical aperture (NA) of 0.42 over the operating temperature range from -54°C to 95°C. The NA is defined by the equation

$$NA = \sin\theta \quad (1)$$

where θ is the half angle of the emission cone, or the smallest angle between the cone and its symmetry axis. The half angle for an NA of 0.42 is 25°.

(1) Ben R. Elmer, "Fiber Optics Transmitter Integrated Circuit Development", Final Technical Report No. AFAL-TR-78-107, July 1978, AD A071437

SECTION III

TRANSMITTER MODULE APPLICATION INFORMATION

The transmitter module was delivered in a metal housing with the I.C. packaged in a hermetically sealed, leadless chip carrier and the LED packaged in a hermetically sealed, TO-46 window can. The transmitter provides for mounting directly to a printed circuit board or a panel through a "D" shaped hole. The transmitter module must have a heat sink for operation above 95°C ambient temperature.

PACKAGE CONFIGURATION

The physical dimensions of the module are displayed in Figure 2. The pin assignment is shown in Figure 3, the Transmitter Pin Connection Diagram.

P.C. BOARD MOUNTING

No special shielding or ground techniques are needed. A good ground path should be provided for the ground pin. Two 2-56 threaded holes are provided in the bottom of the housing for securing the transmitter module to the printed circuit board.

WARNING

Care should be taken that the mounting screws do not extend into the module beyond the maximum allowed penetration depth of .060 inches. Damage may result to components inside the module if screws extend beyond the maximum allowed penetration depth.

POWER SUPPLY FILTERING

No decoupling capacitors are needed on the V_{cc} line to ground. Power supply AC decoupling is performed inside the module to enhance the utility of the transmitter modules.

HEAT SINKING

No heat sinking is required for the transmitter module over the operating temperature range of -54 to 95°C if adequate ventilation is available. Ventilation is adequate when the module's environment can dissipate 677mW of heat from the module and raise the temperature around the module to no

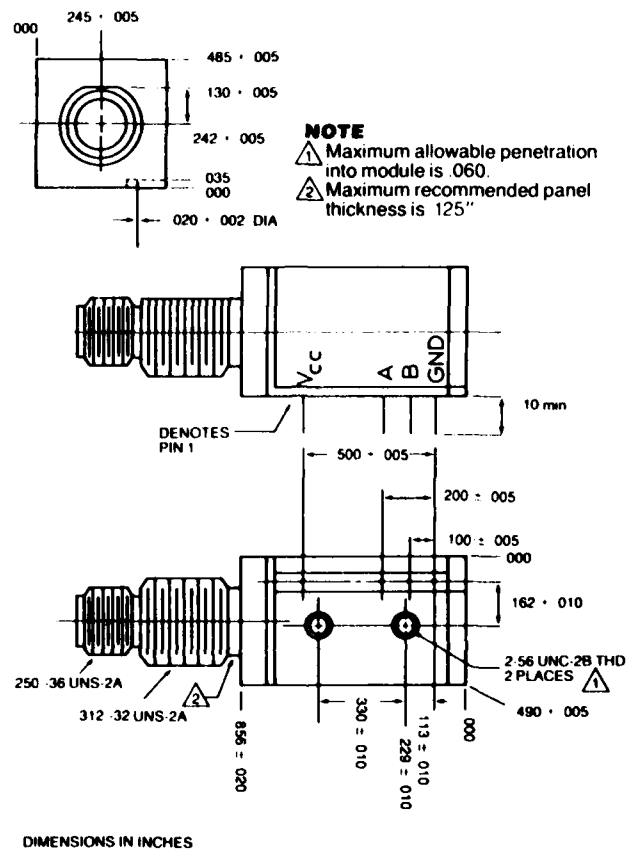


Figure 2.
Transmitter Module
Package Configuration

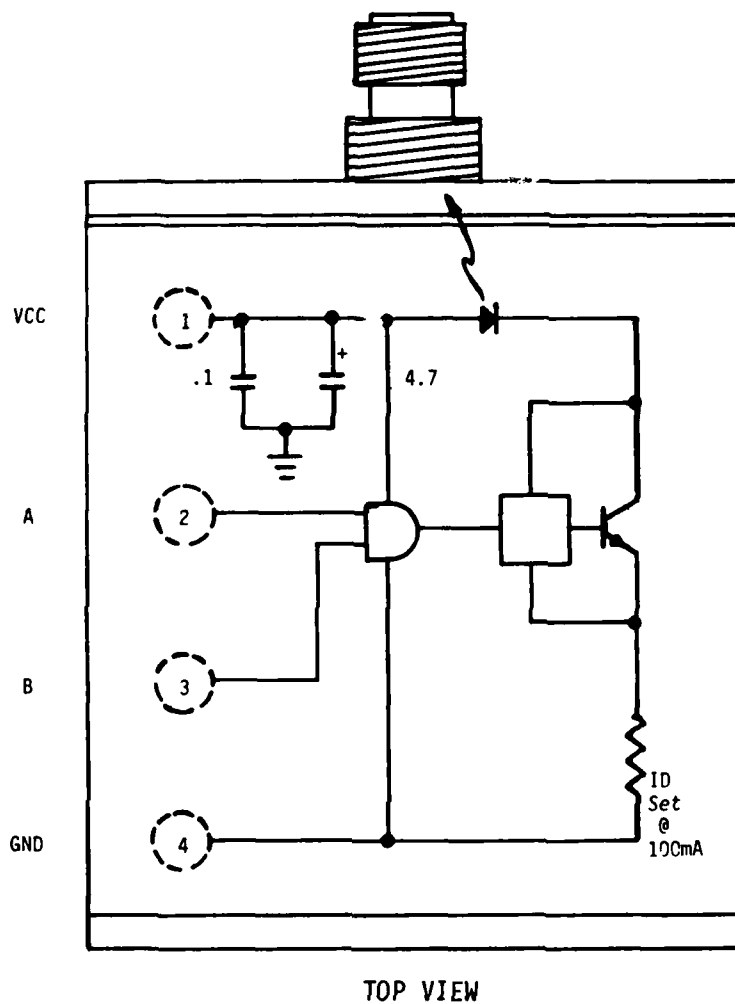


Figure 3
Transmitter Pin Connection Diagram

more than 95°C. Heat sinking the transmitter module will reduce LED junction temperature and will increase the transmitter module's life.

For operation from 95 to 125°C a good heat sink is required. Panel mounting to a metal panel is the best method of providing a heat sink for the transmitter module. If the module is mounted to a printed circuit board a heat sink should be used which provides a thermal resistance of 7°C/W or less at 125°C ambient temperature from the housing to the ambient environment.

The typical transmitter module with LED operating at 100% dissipates 677mW. The LED junction temperature, using a heat sink that has a thermal resistance of 7°C/W, will be 147.7°C if the operating environment is 125°C. The same heat sink, when the LED is operating at 50% duty cycle, will reduce the LED junction temperature to 132.1°C.

ELECTRICAL CHARACTERISTICS

The performance characteristics of Table 2 shall apply over the operating temperature range -54°C to 95°C and for a supply voltage of 5 volts \pm 10 percent.

Table 2
Maximum Ratings

Parameter	Value	Units
Supply Voltage, V_{cc}		
Operating	4.5 to 5.5	V
Non-operating	7.0	V
Input Voltage (either input)	5.5	V
Supply Current, I_{cc}	155	mA
Temperature, Ambient (TA):		
Operating	-54 to 95	°C
Non-operating	-65 to 150	°C
Power Dissipation, P_D	852.5	mW
Lead Temperature (soldering 10 sec)	260	°C

INPUT CHARACTERISTICS

The input current and voltage levels shall be TTL compatible as specified in Table 3. Each input shall appear to be one standard 5400 series TTL input load.

Table 3
Input Characteristics

Parameter	Test Condition	Min.	Typical	Max.	Unit
High-level input voltage, V_{IH}	---	2.0	2.4	---	V
Low-level input voltage, V_{IL}	---	---	0.4	0.8	V
Input clamp voltage, V_I	$V_{CC} = 4.5V$	---	-1.2	-1.5	V
Input current at maximum input voltage, I_I	$V_{CC} = 5.5V, V_I = 5.5V$	---	0.001	1	mA
High-level input current, I_{IH}	$V_{CC} = 5.5V, V_I = 2.4V$	---	1.0	40	μA
Low-level input current, I_{IL}	$V_{CC} = 5.5V, V_I = 0.4V$	---	-1.2	-1.6	mA

Table 4 lists the optical characteristics of the transmitter module. The transmitter module couples at least 750 micro watts of radiant power into an NA of 0.42 with an optical aperture diameter of .045 inches over the temperature range of -54°C to 95°C.

Table 4
Optical Output Characteristics

Parameter	Conditions	Min	Typ	Max	Units
High-level RPO	$V_{CC} = 5V, V_I = 2.4V$	0.75	---	3.0	mW
Low-level RPO	$V_{CC} = 5V, V_I = 0.4V$	---	---	.5	μW
RPO Uniformity	.045 inch dia. aperture	50	---	---	%
Peak Output Wavelength	$I_D = 100mA$	---	825	---	nM
P_o temperature coefficient		---	-.012	---	dB/°C
Optical aperture size, dia.		---	.045	---	inches

AC SWITCHING CHARACTERISTICS

The AC switching characteristics from the input voltage to the optical output signal shall be in accordance with Table 5 and Figure 4. The data rate of the transmitter module shall be between DC and 10Mbits/sec (Manchester).

Table 5
Switching Characteristics
Transmitter Module

Parameter	Min	Max	Units
Input Transition Time Low-to-High T_{ILH}	4	6	nsec
Input Transition Time High-Low T_{IHL}	4	6	nsec
Delay Time Low-to-High T_{DLH}		20	nsec
Delay time High-to-Low T_{DHL}		20	nsec
Output Transition Time Low-to-High T_{OLH}		20	nsec
Output Transition Time High-to-Low T_{OHL}		20	nsec
Input Pulse Width T_1	40		nsec
Output Pulse Width T_3	$T_1 - 7$	$T_1 + 7$	nsec

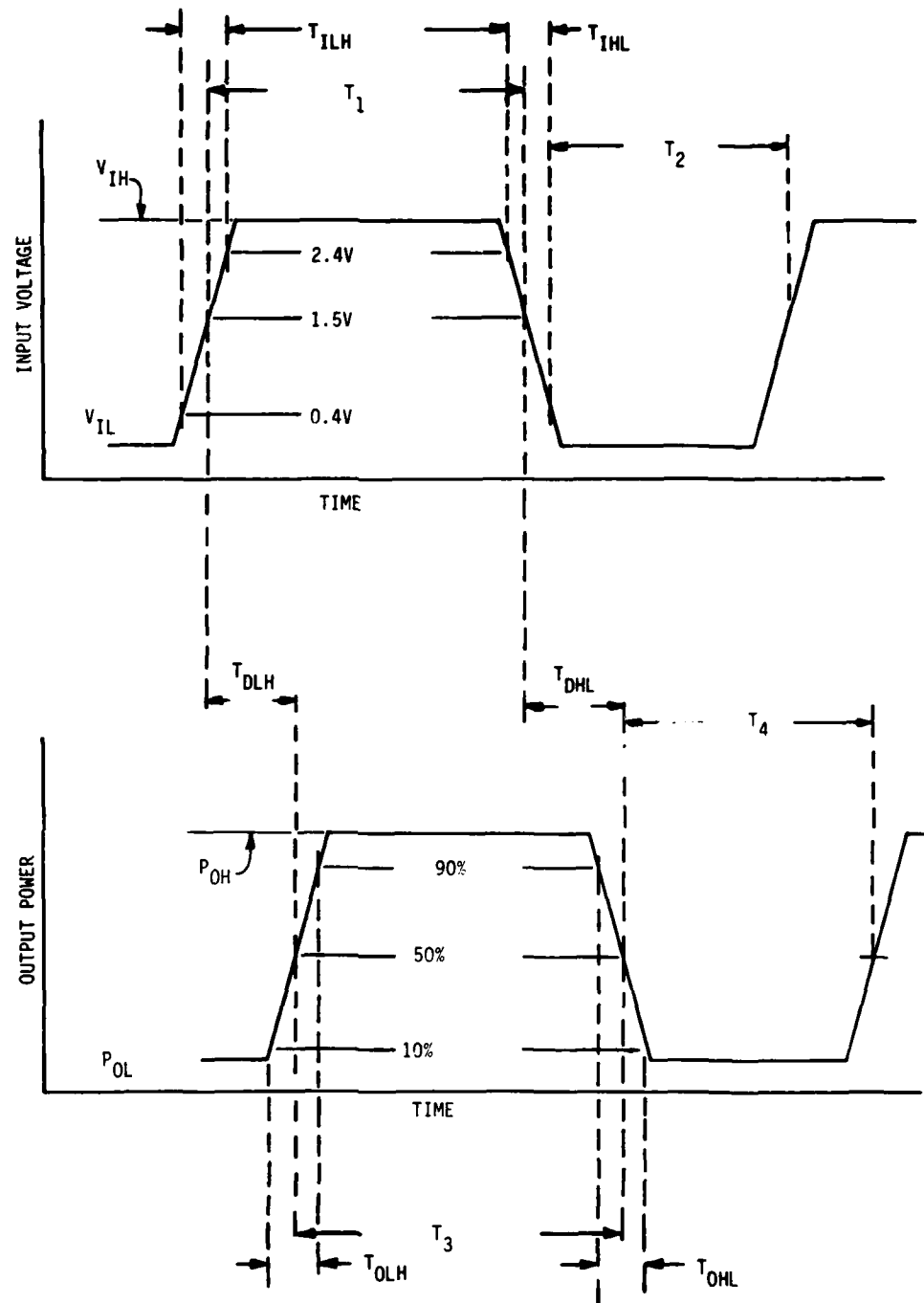


Figure 4.
Input/Output Waveform
Characteristics

PREDICTED COUPLED POWER INTO FIBER OPTIC CABLES

The transmitter module's radiant power output (RPO) is measured at a numerical aperture (NA) of .42 through a .045 inch diameter aperture. If the percent of the measured RPO is known in relation to NA, the coupled radiant optical power into a fiber optic cable can be predicted. The curve in Figure 5 shows the percent of optical power versus the NA for the SPX 4146 LED used in the transmitter module.

Assuming a perfect collimated light source, then the light coupled for a fiber smaller than the source is:

$$P = \left(\frac{\text{Area of Fiber Core}}{\text{Area of Light Source}} \right) \times (\text{Power of Source}) \quad (2)$$

This reduces to

$$P = P_S \left(\frac{D_C}{D_A} \right)^2 \quad (3)$$

Where P_S is the optical output of the transmitter, D_C is the diameter of the fiber core, and D_A is the diameter of the aperture.

POWER COUPLED FOR A SINGLE FIBER OPTIC CABLE

The theoretical power that the transmitter will couple into a single optical fiber is just equation 3 multiplied by the NA correction factor (F_{NA}).

$$P_{SF} = P_S \left(\frac{D_C}{D_A} \right)^2 \cdot F_{NA} \quad (4)$$

F_{NA} can be found from the graph in Figure 5 by knowing the NA of the fiber. The F_{NA} is the percent of RPO from the graph divided by 100. The transmitter module's RPO is specified at an NA of .42, so 100% of the power is found within an NA of .42.

POWER COUPLED FOR A BUNDLE FIBER OPTIC CABLE

The power coupled into a bundle fiber optic cable from the transmitter module is just the sum of all the fiber's cores areas divided by the area of the light source, multiplied by the radiant power output of the transmitter.

If N is the number of optical fibers within the bundle, the power coupled for fiber optic bundle cable is:

$$P_{\text{BUNDLE}} = P_S \cdot N \cdot \left(\frac{D_C}{D_A} \right)^2 \cdot F_{\text{NA}} \quad (5)$$

Equations 4 and 5 assume a perfectly polished and clean fiber optic cable. The actual coupled power into the fiber optic cable may be as much as 2dB less than the theoretical value due to imperfections in the fiber termination.

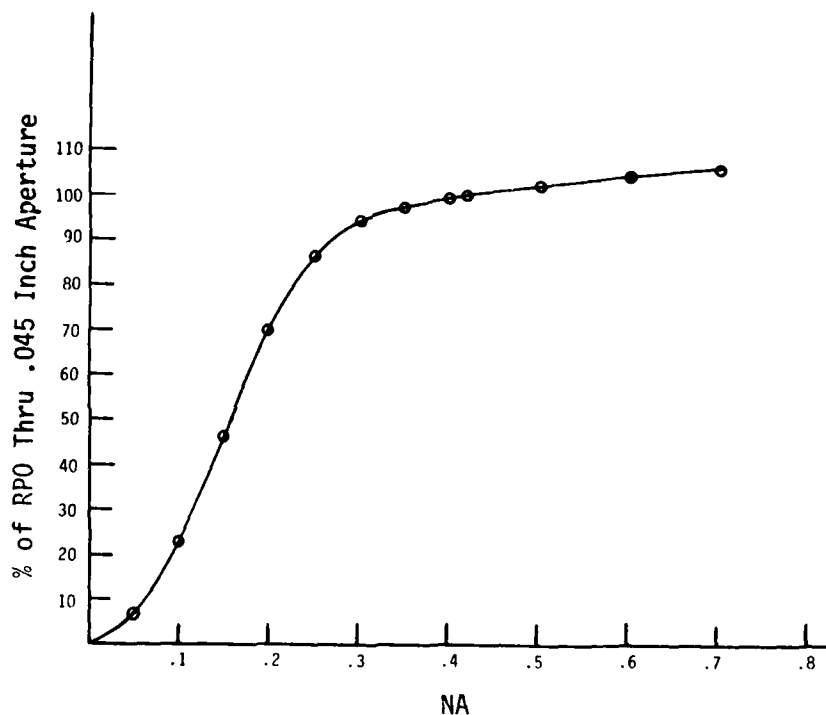


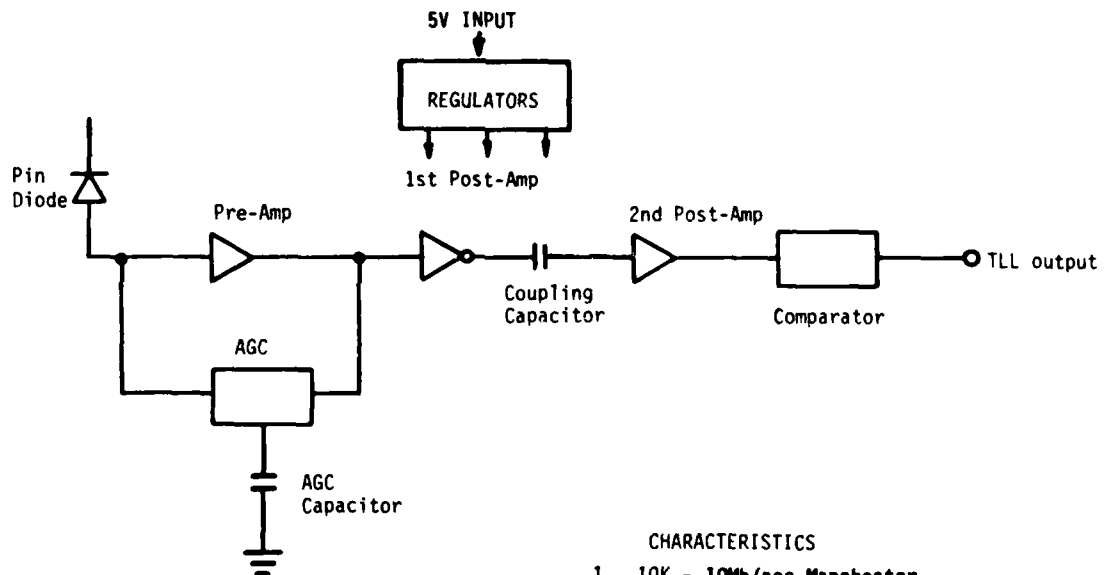
Figure 5
Transmitter Power Vs NA

SECTION IV

RECEIVER CIRCUIT DESCRIPTION

Figure 6 is a block diagram of the receiver module with a list of important performance characteristics.

The primary function of the receiver module is to convert optical signals into digital signals. A PIN diode converts the optical pulses into a low level signal current that is amplified by a pre-amplifier whose gain is set by the AGC circuit. These electrical signals are converted to standard TTL logic digital signals.



CHARACTERISTICS

1. 10K - 10Mb/sec Manchester
2. Sensitivity .4 μ Watt
3. Optical Signal Range = 30dB Power
4. 10^{-8} Bit Error Rate

Figure 6

Fiber Optic Receiver Module Block Diagram

The receiver module, with its sensitivity, dynamic range, and 10K to 10Mbits/second data rate range, provides a general purpose module for use in various length point-to-point links. The important characteristics of the Receiver Module are:

- Pre-amp AGC
- AC coupling
- TTL output

PRE-AMP AGC

The automatic gain control (AGC) for the receiver module operates on the pre-amp itself to adjust its gain in order to extend the dynamic range beyond limitations placed on a fixed gain preamp. The dynamic range can be thought of in terms of the photodiode current, or:

$$\text{dynamic range} = 20 \log \frac{I_{\text{MAX}}}{I_{\text{MIN}}} \quad (6)$$

When the range of input optical signal is considered, the dynamic range is more appropriately referred to as the optical signal range (OSR)² or the range of power (light) into the receiver detector.

$$\text{OSR} = 10 \log \frac{P_{\text{in max}}}{P_{\text{in min}}} = 10 \log \frac{.4\text{mW}}{.4\mu\text{W}} = 30 \text{ dB power} \quad (7)$$

This large OSR of 30 dB is a direct result of the pre-amp AGC circuit. The Pre-Amp AGC uses an AGC capacitor of .01 μF to maintain a voltage proportional to the average input signal swing, which in turn essentially controls the gain of the pre-amp. The AGC capacitor charges through the effective resistance of 40K Ω . The start-up time from a signal's entering the receiver module until valid data is obtained as output of the pre-amp is determined by the time constant of the AGC capacitor. One AGC time constant is

$$\tau = RC = (40\text{K}\Omega) (.01\mu\text{F}) = .4 \text{ ms}$$

The AGC capacitor should reach its average signal voltage within five time constants

$$\text{OR } 5\gamma = 5(.4\text{ms}) = 2 \text{ ms.}$$

So the pre-amp AGC would receive its first valid data approximately 2ms after the time the input signal started.

AC COUPLING

If a pre-amp is DC coupled to a post-amp, the drift associated with temperature and supply variations may be significantly larger than the input noise. The threshold must then be set much larger than the noise level to allow for the drift in the pre-amp and, therefore, seriously affects receiver sensitivity. The use of AC coupling in the module allows for improved sensitivity.

The AC coupling limits the input format to one that has a constant average value over all time intervals. NRZ coding with long strings of 1's or 0's cannot be used for the Receiver Module. Any encoding scheme, such as Manchester,³ which has a constant average value of the signal over time must be used.²

The AC coupling capacitor has a value of $1.0\mu\text{F}$. There is a $1.5\text{K}\Omega$ resistor to ground. So, one time constant is

$$\gamma = RC = (1.5\text{K}\Omega) (1\mu\text{F}) = 1.5\text{ms}$$

The AC coupling time constant must be equal to or greater than the AGC time constant for proper circuit performance. The receiver module AC coupling's time constant is 3.75 times the AGC time constant.

The AC coupling capacitor will reach its signal average value in about five time constants,

$$\text{OR } 5\gamma = 5(1.5\text{ms}) = 7.5 \text{ ms.}$$

Therefore, the response time of the receiver module is due largely to the AC coupling capacitor. So, the receiver module would receive valid data on its output pin 7.5ms after the time the input signal started.

TTL OUTPUT

One of the important features of the receiver module is its TTL output. A comparator stage referenced to ground is used to translate the signal from the post amp into a ground referenced signal which is then fed into a TTL output stage. The output is compatible with the 5400 series TTL logic family.

SECTION V

RECEIVER MODULE APPLICATION INFORMATION

The receiver module was delivered in an all-metal housing with the I.C. and the photodiode hermetically sealed. The receiver package provides for mounting directly to a printed circuit board or a panel through a "D" shaped hole. The receiver module is a self-sufficient device that requires no special trim pots for adjustments or additional components. The receiver module is intended to be used as a general purpose receiver for point-to-point links.

PACKAGE CONFIGURATION

The physical dimensions of the module are given in Figure 7 and the electrical pin assignments are given in Figure 8.

P.C. BOARD MOUNTING

No special shielding is needed. A good ground path should be provided for the two ground pins. Two 2-56 threaded holes are provided in the bottom of the housing for securing the receiver module to the Printed Circuit Board. The ground path should also be connected to these screws.

WARNING

Care should be taken that the mounting screws do not extend into the module beyond the maximum allowed penetration depth of .060 inches. Damage may result to components inside the module if screws extend beyond the maximum allowed penetration depth.

PANEL MOUNTING

Inside the receiver module, the ground is tied to the module metal housing. If a number of receiver modules are panel mounted, a ground loop problem may exist. To avoid this problem, the receiver module should be electrically isolated from the panel with insulating washers to avoid ground loops.

POWER SUPPLY FILTERING

The power supply requirements are $V_{CC} = +5 \pm 10\%$ and $V_O = 90 \text{ V max.}$ Decoupling capacitors are not needed because decoupling is performed inside the module to enhance its utility.

HEAT SINKING

No heat sinking is required for the receiver module.

DEVICE ELECTRICAL SPECIFICATIONS

Electrical Characteristics

The performance characteristics shall apply over the operating temperature -54°C to 95°C .

DC Performance Characteristics

The maximum ratings of the receiver module are listed in Table 6. The input characteristics are as specified in Table 7.

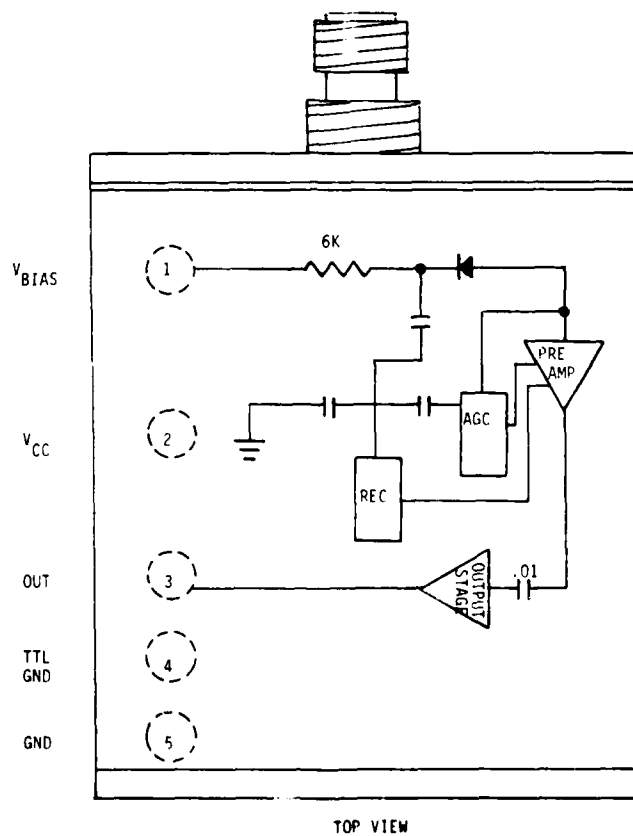


Figure 8
Receiver Pin Connection Diagram

Table 6
Maximum Ratings

Parameter	Value	Units
Supply Voltage, V_{cc}		
Operating	4.5 to 5.5	Volts
Non-operating	7	Volts
Supply Current, I_c		
Operating	55	mA
Non-operating	70	mA
Output Short Current	55	mA
Supply Voltage, V_D (Photodiode)	90	Volts
Temperature		
Operating	-54 to 95	$^{\circ}\text{C}$
Non-operating	-65 to 150	$^{\circ}\text{C}$
Power Dissipation, P_d	385	mW
Lead Temperature (soldering 10 sec)	260	$^{\circ}\text{C}$

Table 7
Input Characteristics

Parameter	Min	TYP	Max	Units
Optical Signal Range (OSR)	30			dB
Optical PIN	.4		400	μ W
Peak Wavelength Response		907		nM

Table 8
TTL Output Characteristics

Parameter	Test Conditions	Min	Max	Unit
High Level Output Voltage V_{OH}	$V_{CC} = 4.5V$	2.4		V
High Level Output Current I_{OH}	$V_{OH} = 2.4V$		400	μ A
Low Level Output Voltage V_{OL}	$V_{CC} = 5.5V$ $I_{OL} = -16$ mA		0.4	V
Low Level Output Current I_{OL}	$V_{CC} = 4.5V$		-16.0	mA
Short Circuit Output Current	$V_{OH} = 2.4$ V min. before shorting		-55	mA

TTL LOADING

The receiver module output will drive ten 5400 type TTL inputs as shown in Figure 9; however, it is recommended that the total number of loads on the output be limited to two TTL loads or less. Reducing the loading both in capacitance and the number of TTL loads on the module's output increases receiver module input sensitivity range by reducing the effective input noise. TTL output characteristics are listed in Table 8.

AC PERFORMANCE CHARACTERISTICS

The switching characteristics from the optical input to the output voltage of the receiver module are specified in Table 9 and Figure 10.

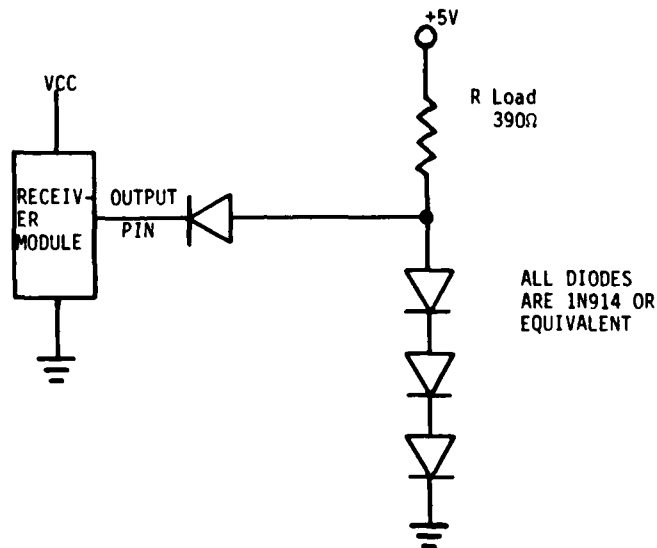


Figure 9
Output Equivalent Circuit
for 10 TTL Loads

Table 9
Switching Characteristics

Parameter	Min	Typ	Max	Units
Data Rate (Manchester Coded Data)	10^4		10^7	bits/sec
Bit Error Rate			10^{-8}	
Propagation Delay Time to High Output Level T_{DLH}		65	75	ns
Propagation Delay Time to Low Output Level T_{DHL}		60	75	ns
Output Transition Time Low-to-High T_{OLH}		7	15	ns
Output Transition Time High-to-Low T_{OHL}		2	15	ns

NOTE: 1.) All measured with the standard load in Figure 9.
2.) All measured with Optical Power input $\geq .4 \mu\text{Watt}$.

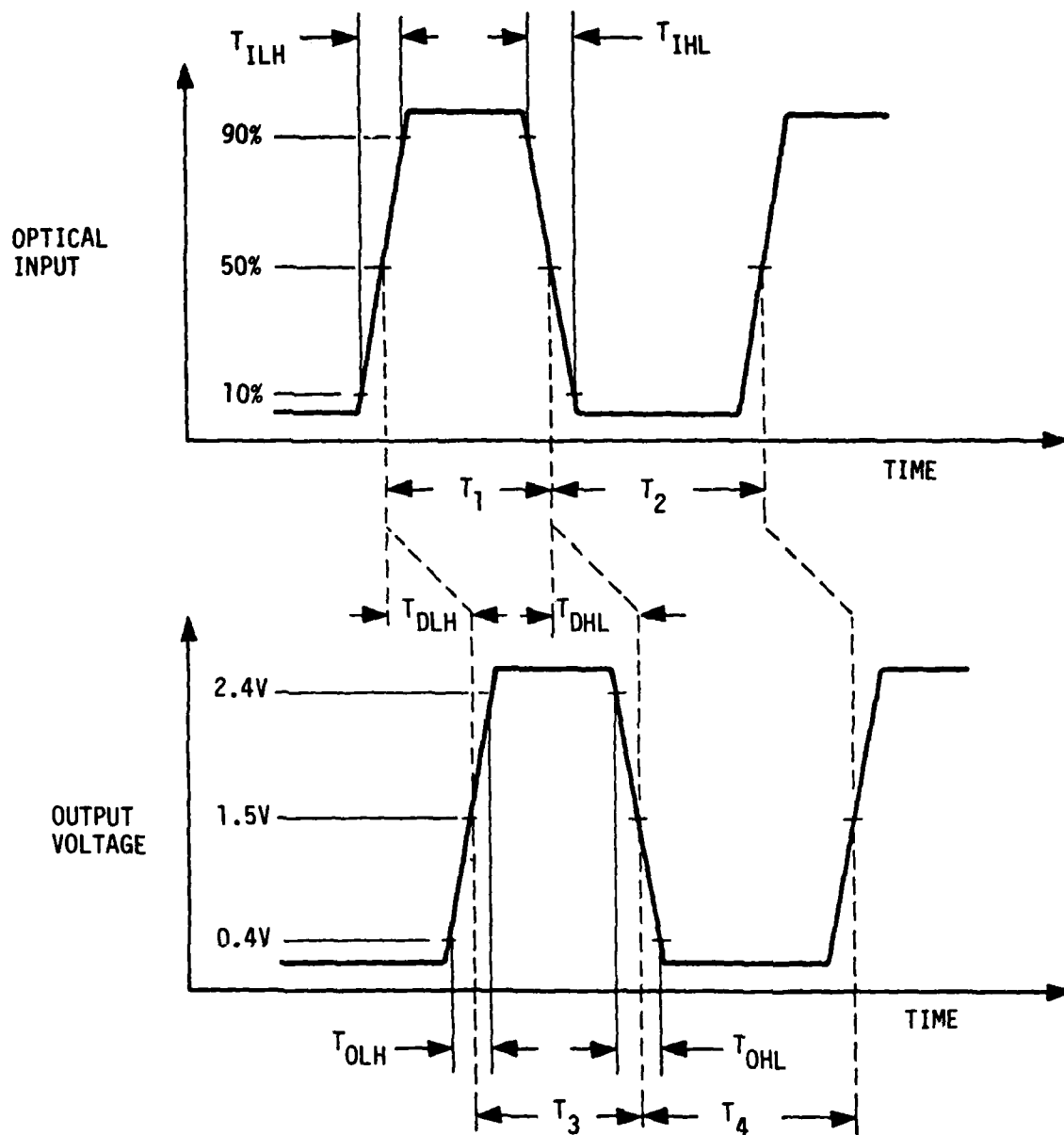


Figure 10
Receiver Input/Output
Risettime Definitions

SECTION VI

MODULE THERMAL CHARACTERISTICS

In a module having less than three square inches of radiating and convecting surface to control the module temperature, the thermal considerations of the module design are very important. Only the transmitter module is considered in the analysis because the receiver module generates less heat than the transmitter module. The two sources of heat are the transmitter I.C. chip and the LED. Thermal paths between the I.C. chip and the environment, and between the LED and the environment were evaluated. Figure 11 illustrates the major thermal conduction paths from the two heat sources.

In the early stage of module package design, a computer simulation of the module thermal design was performed using conservative estimates. The computer simulation quickly pointed out the junction temperature of the module's LED and the I.C. chip would be above the maximum allowed value of 150°C at an operating environment temperature of 125°C . At the MIL-E-5400 Class 3 maximum ambient environment of 95°C , the transmitter module will operate with no difficulty.

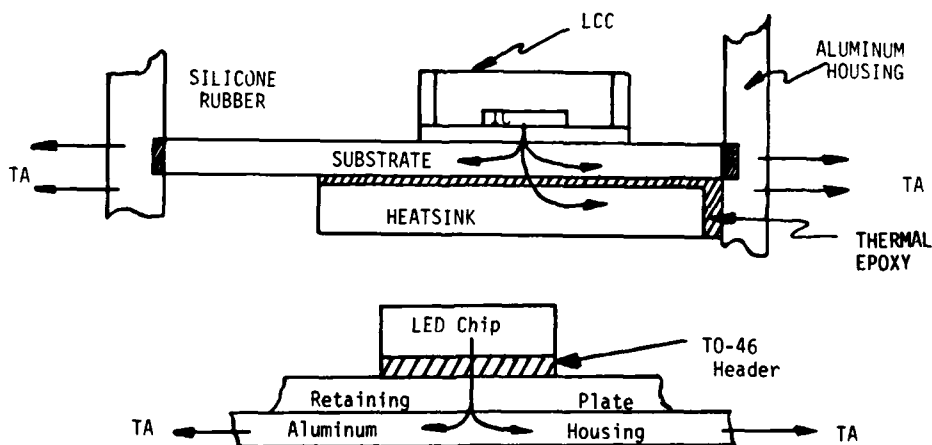


Figure 11
Major Thermal Paths for Transmitter Module

After modules were assembled, the thermal characteristics of a module were measured using a small thermocouple. The actual housing, retaining plate, and ceramic substrate temperatures were measured with the module under different operating modes at 25°C and 95°C ambient temperature. A corrected thermal model of the transmitter module was developed and is shown in Figure 12.

Figure 13 is a thermal profile of the Transmitter Module. Condition A of Figure 13 shows the integrated circuit driver chip junction temperature at 116.4°C. This is for the normal operating mode of the Transmitter Module operating with the LED pulsed at a 50% duty cycle. Condition B of Figure 13 is the Transmitter thermal profile with the input to the transmitter held in the logic "1" TTL state, forcing current through the LED 100% of the time. Bar graphs for conditions A and B are based on measured values for a typical Transmitter Module. The bar graph for Condition C is the same as Condition B except using the worst possible conditions for the module and extrapolating from the measured values in Condition B.

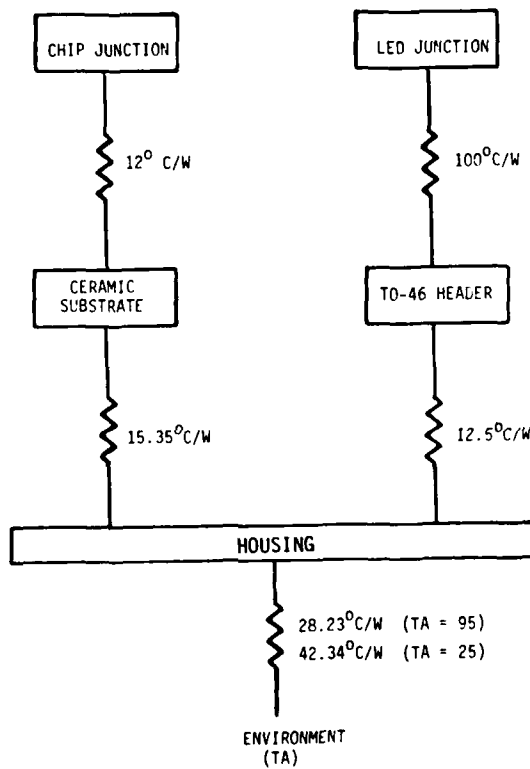


Figure 12
Transmitter Module Thermal Resistance Model

MIL-E-5400 CLASS 3

- ⑥ = Chip Junction
- ⑤ = LED Junction
- ④ = Substrate
- ③ = 70-46 Header
- ② = Housing
- ① = Environment

CONDITION

- A Typical unit with 100mA
50% duty cycle LED, $V_f = 1.6$ Volts
- B Same unit as in A but with LED
turned on 100% of time
- C Theretical max. possible value condition
with LED turned on 100% of time

MEASURED

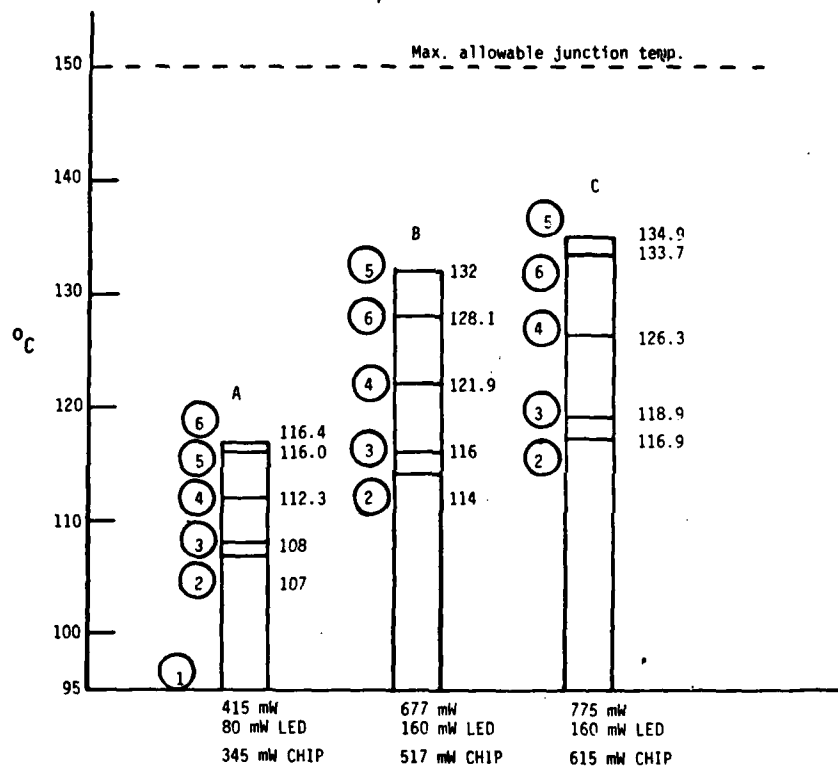


Figure 13
Transmitter Module Thermal Profile

SECTION VII

COMPONENT SPECIFICATIONS AND TEST PLAN

The module has as its basic components the LED or photodiode and an integrated circuit. The other components are the resistors and the capacitors. The resistors are deposited, laser trimmed resistors on the ceramic substrate. The capacitors are solid state, ceramic, or tantalum construction.

TRANSMITTER MODULE COMPONENTS

The major components of the transmitter module are the SPX-4146 LED and the Fiber Optic Transmitter Integrated Circuit (FOTIC) packaged in a Leadless Chip Carrier.

LED

The SPX-4146 is a high radiance, GaAlAs, IR LED. Its unique integrated optical element projects a uniform .045 inch diameter spot at the window surface. The LED is packaged in a hermetically sealed TO-46 Window Can. Figure 14 illustrates the package configuration of the SPX-4146 LED.

FOTIC

The FOTIC was developed for the Air Force under contract F33615-76-C-1280. More detailed information concerning it may be found in the Final Report, AFAL-TR-78-107.¹ The FOTIC is packaged in a Leadless Chip Carrier (LCC) and its terminal assignment and package configuration is illustrated in Figure 15.

RECEIVER MODULE COMPONENTS

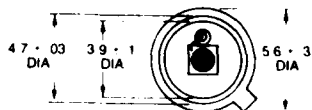
The major components of the receiver module are the SPX-4145 photodiode and the Fiber Optic Receiver Integrated Circuit (FORIC) packaged in a LCC.

PHOTODIODE

The SPX-4145 is a high speed fiber optic photodiode that typically exhibits a 1 μ s risetime at bias voltage of 90 Volts. The SPX-4145 LED is packaged in a hermetically sealed TO-46 window can. The SPX-4145 package configuration is illustrated in Figure 16.

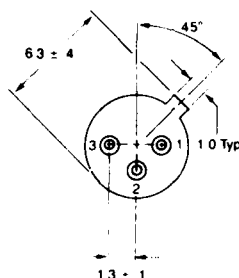
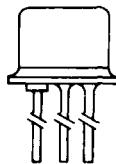
FORIC

The FORIC was developed for the Air Force under contract F33615-76-C-1275 and more detailed information may be found in Final Report AFAL-TR-78-185.² The FORIC is packaged in a hermetically sealed LCC. Its terminal assignment information is shown in Figure 17.



NOTES:

- 1 Anode & cathode insulated from case
- 2 PIN1 — anode (P-type), PIN2 — cathode (N-type), PIN3 — case (ground)



ALL DIMENSIONS IN MILLIMETERS

Figure 14
SPX-4146 LED Package Configuration

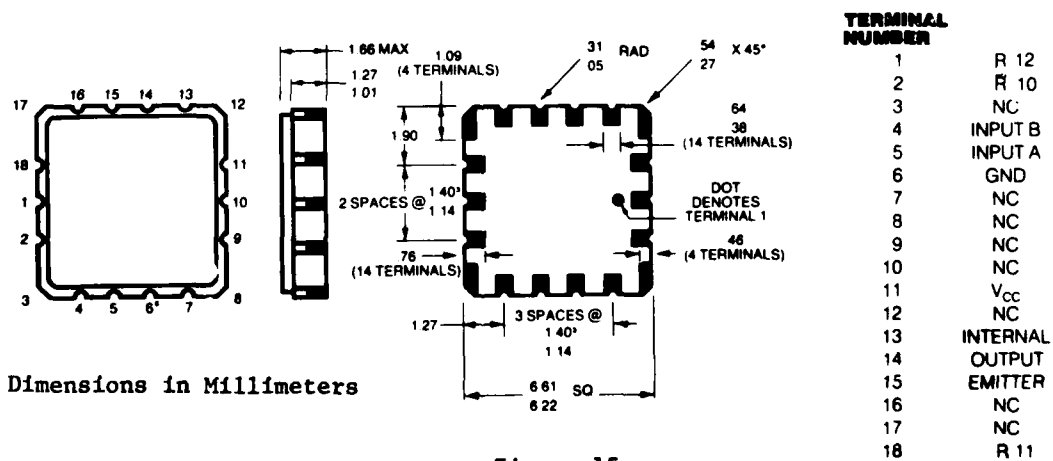
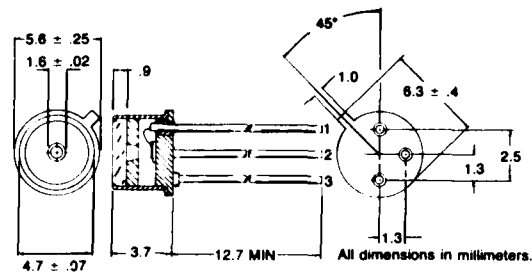


Figure 15
FOTIC LCC Terminal Assignment



Notes

1. Anode and Cathode insulated from case.
2. Pin 1 — Anode (P-type). Pin 2 — Cathode (N-type). Pin 3 — case (Ground).

Figure 16
SPX-4145 Package Configuration

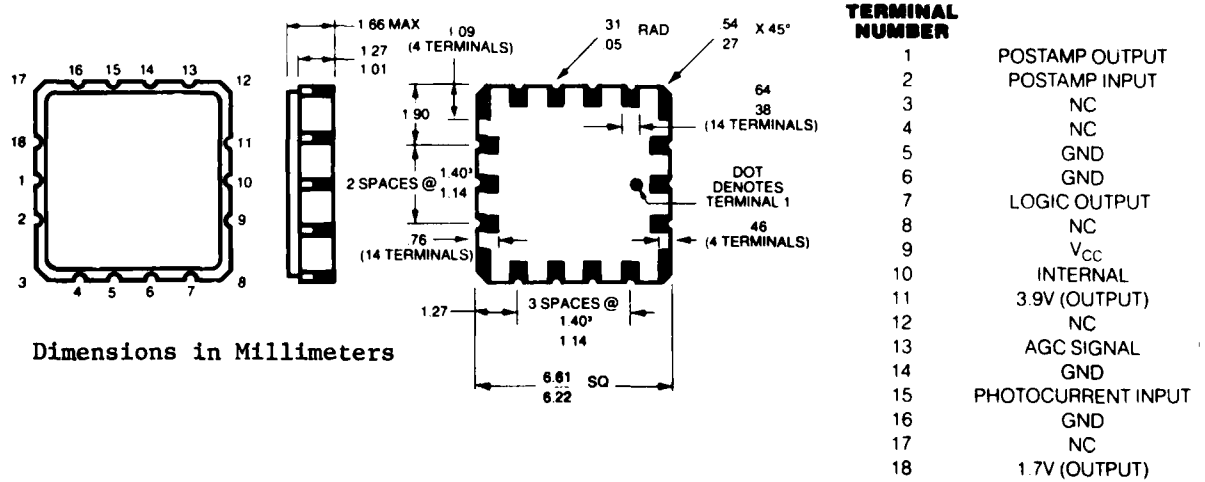


Figure 17
FORIC LCC Terminal Assignment

COMPONENT TEST PLAN

The FORIC and FOTIC components were tested to Table 9 before assembly into the modules.

Table 10
MIL-STD-883A Environmental Tests for
Transmitter and Receiver L.C.C.'s

Description	Method	Condition
Internal visual	2010.1	B
High-temperature storage	1008.1	C, 24 hr
Temperature cycling	1010.0	B
Constant acceleration	2001.1	E, Y, axis only
Fine and gross leak	1014.1	---
Burn-in test	1015.1	B, 168 hr
External visual	2009.1	---

The module, LED, and photodiode devices were screened to Table 10 tests before being assembled into the Modules.

TEST RESULTS

The LED components had an 81.4% yield of the total number screened to Table 10. 11.4% of the LED components failed electrical test after thermal shock of 0°C to 100°C. Half of those failed changes in reverse breakdown voltage and the others failed for low light power output with the LED biased at 100mA. 2.9% of the LED components failed fine leak test after acceleration per MIL-STD-750A method 2006, 15,000 G's in Y¹ and Y² directions. 1.4% of the LED components failed electrical test after variable frequency vibration per MIL-STD-750A, method 2056, 30G's was performed. The remaining 2.9% failed

electrical test after mechanical shock per MIL-STD-202, method 213 at 100G's. One additional test was performed on the LED components, the uniformity of the radiant power output was measured.

LED UNIFORMITY

The uniformity of the modules' Radiant Power Output (RPO) was measured by measuring the LED components before assembly into the modules. The uniformity of RPO is defined as the ratio of minimum to maximum RPO divided by the specified optical aperture into the specified emission cone within the specified emission range. This ratio is equal to or greater than 50% for acceptance. This test was performed by using a video closed circuit TV system. The camera was focused on the lens of the LED through a 45 mil aperture. The video information was displayed on an oscilloscope. A single line of the video display was scanned across the LED and the minimum and maximum points were noted. A graph of the single line was displayed on the oscilloscope. The LED was scanned horizontally across its face then the LED was rotated 90° and scanned again. A typical LED single line graph is shown in Figure 18 for several positions on the LED. The corresponding TV monitor view of the LED is shown also.

PHOTODIODE

The photodiode components were screened to Table 11 and it was found that about 50% of the devices survived these tests. An additional run of photodiode components was processed to complete the component requirement to assemble the receiver modules.

There was a serious yield problem with the SPX 4145 photodiode. As part of the environmental testing, a 15000G acceleration test in the Y^2 axis was performed and caused 50% of the lot to fail. The heavy metal optical cone that is epoxied to the window came loose and fell against the photodiode chip on the ones that failed. Ten of the photodiode components that had passed the acceleration test were retested at 15000G acceleration to see if a fatigue problem existed. No new failures were detected, so the assumption is that the Y^2 axis acceleration test would eliminate the poorly bonded cone elements.

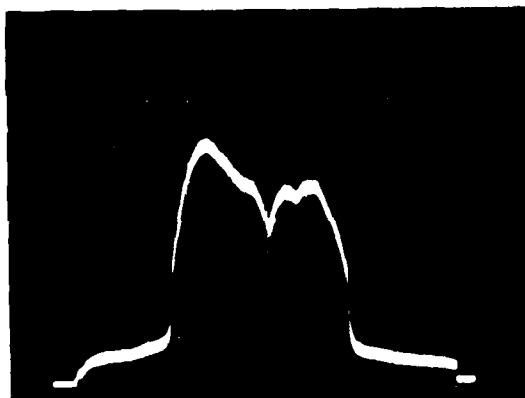
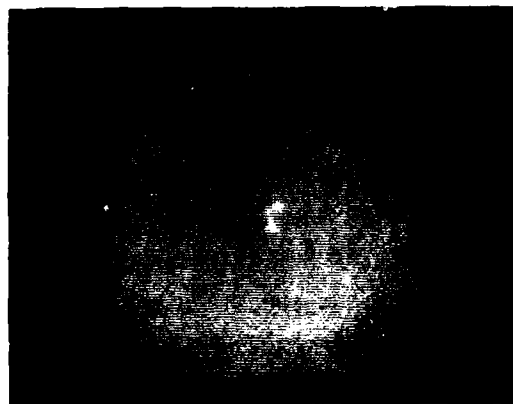
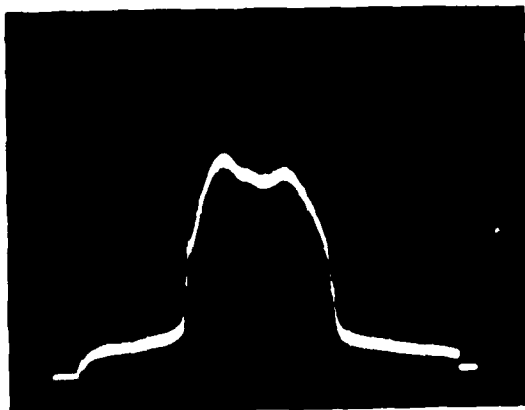


Figure 18
LED Uniformity
36

Table 11
LED and Photodiode Test Plan

TEST DESCRIPTION	MIL-STD-	METHOD	CONDITION	NOTES
Thermal Shock	750A	1056.1	A	5 Complete Cycles
Acceleration	750A	2006	15,000 G's Y ¹ & Y ²	
Fine Leak	202	112	C	Leakage < 50 X 10 ⁻⁸ ATM cc/SEC
Gross Leak	750	1071	C	Step 2
Solderability	750A	2026		LTPD of 15
Vibration	750A	2056	30 G's	
Mechanical Shock	202	213	100 G's	
Moisture Resistance	750A	1021	Non-operating	Lead Fatigue Test Omitted

SECTION VIII

MODULE ASSEMBLY STEPS

Both transmitter and receiver modules use the same housing and are assembled in the same manner. The transmitter module assembly will be discussed first with the use of illustrative photographs.

TRANSMITTER MODULE ASSEMBLY

The major parts of the transmitter module are the ceramic substrate, FOTIC LCC, LED assembly, Housing, and Optical Connector.

TRANSMITTER SUBSTRATE ASSEMBLY

The transmitter module assembly starts with a single-sided ceramic substrate with glass covered Pt - Au metallization. The metallization not covered with glass is solder dipped. The terminals are staked into the substrate for the first assembly operation. The next assembly operation is assembling the components on the substrate. The substrate is placed on a hot stage and the FOTIC LCC is positioned on its correct location while the solder reflows. The two capacitor components are also placed in their correct locations and the solder is reflowed. Additional solder is added to the base of the terminals to ensure that the terminals are soldered to the substrate. The substrate is then removed from the hot stage. Two small gold Kovar tabs are then soldered to the substrate with a small pencil iron. The completed substrate assembly is shown in Figure 19.

LED ASSEMBLY

The LED is epoxied to a retaining plate using an alignment and holding fixture. The fixture controls the centering of the LED component and the distance from the face of the LED lenses to the back of the retaining plate to within $\pm .9$ mil tolerance. The anode and the cathode terminals are clipped off .050 inches from the back of the plate as shown in Figure 20.

TRANSMITTER SUBASSEMBLY

The LED assembly leads are then welded to the gold Kovar tabs of the substrate assembly. The completed transmitter subassembly is pictured in Figure 21.

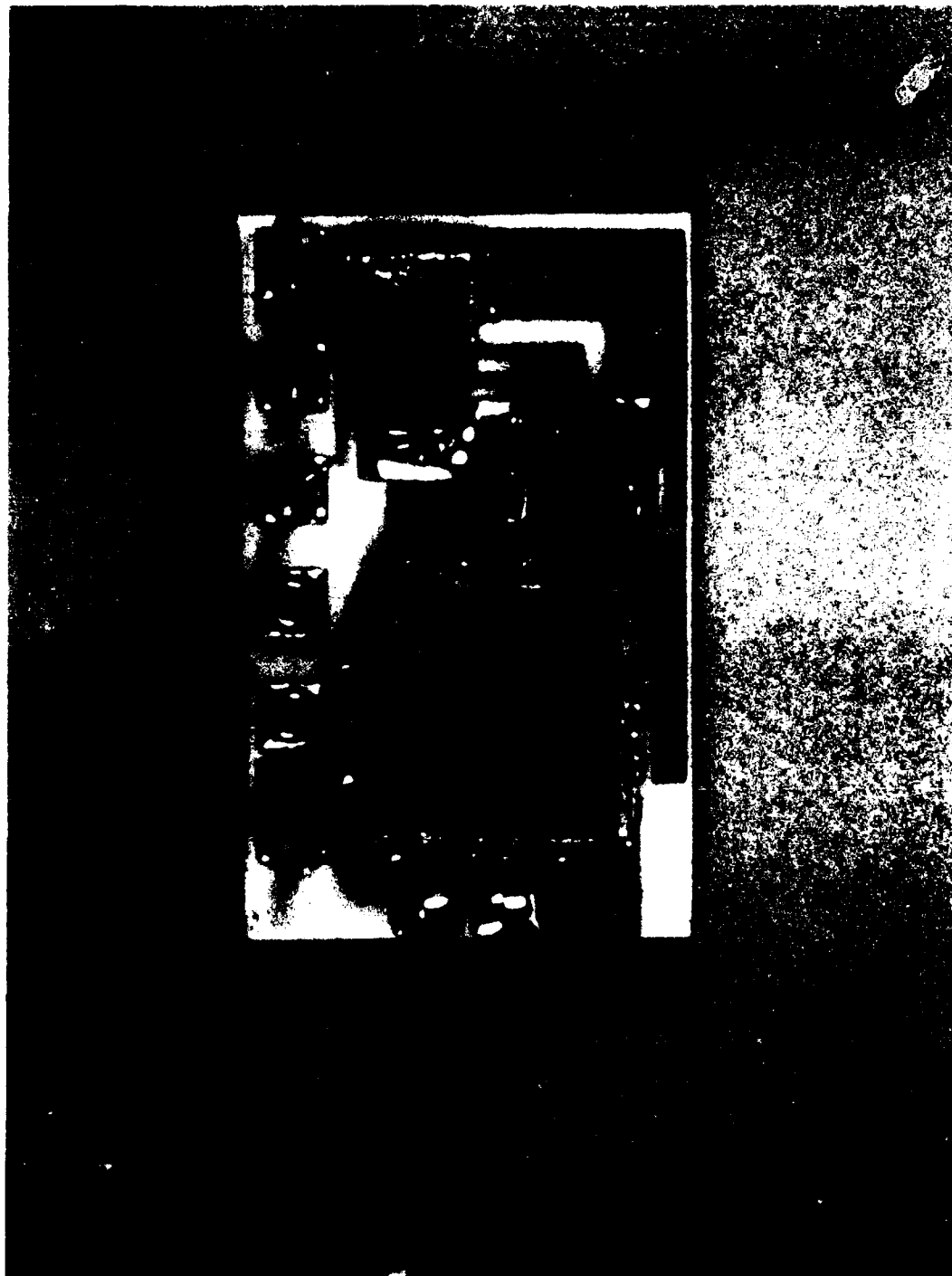


Figure 19
Completed Substrate Assembly



Figure 20
LED Assembly

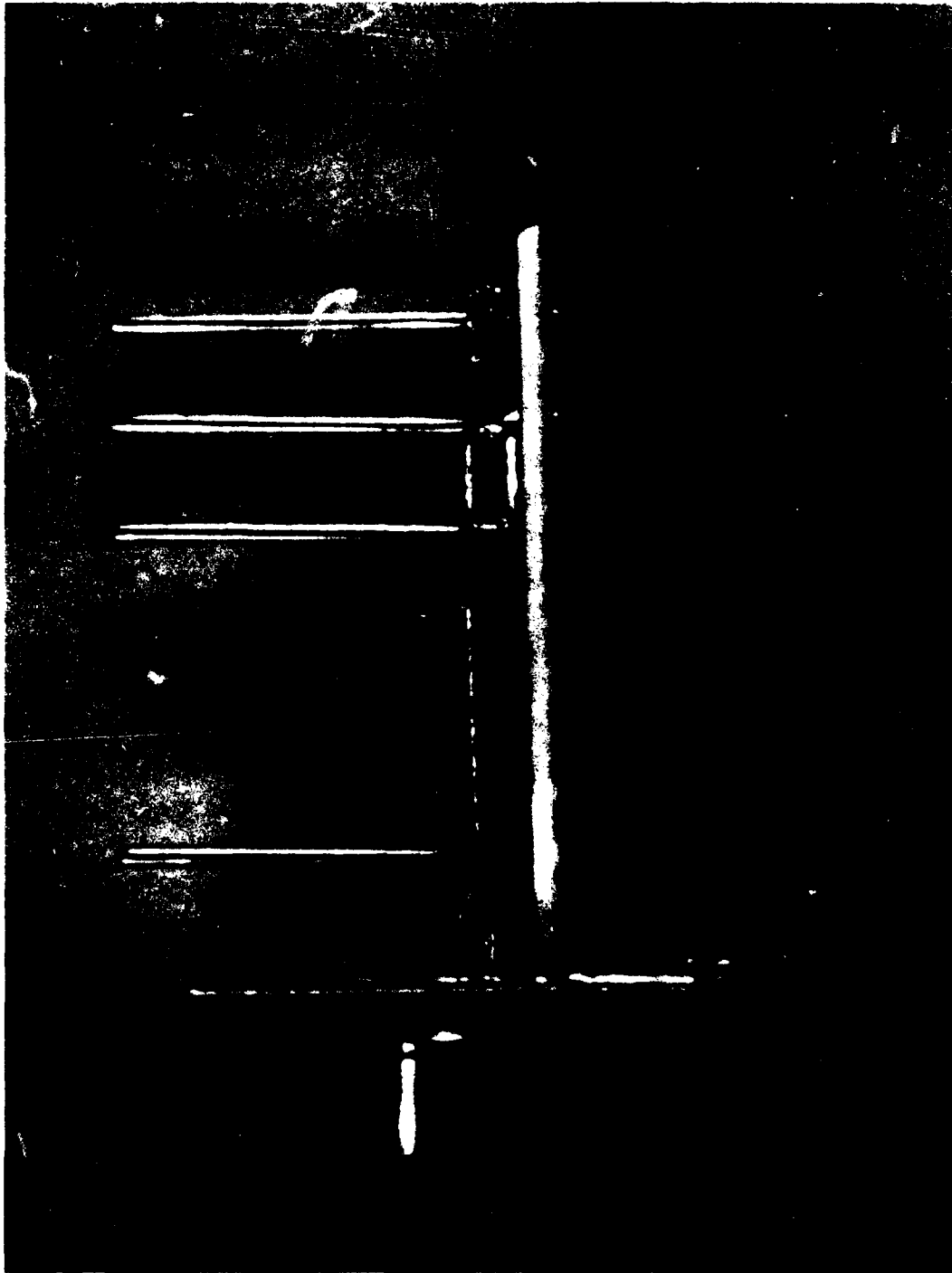


Figure 21
Transmitter Subassembly

TRANSMITTER HOUSING ASSEMBLY

The substrate assembly is then pushed into the slots in the aluminum housing. The substrate is epoxied to the housing with a thermal conducting epoxy. An aluminum bar for a heat sink is epoxied to the back side of the transmitter substrate. The transmitter module is completed by attaching the optical connector and end plate to the housing with three 2-56 screws. The transmitter module is then potted with a clear silicone rubber potting compound. The end view of a completed Transmitter Module with the End Plate removed is shown in Figure 22. The transmitter substrate with its heat sink can be seen embedded in the clear potting compound.

RECEIVER MODULE ASSEMBLY

RECEIVER SUBSTRATE ASSEMBLY

The receiver substrate has metallization on both sides and is solder dipped on one side. Eight positions of the substrate are staked with substrate terminals. The three terminals at the top of the substrate are clipped off close to the substrate. These terminals are used for electrical feedthroughs. The front side of the receiver substrate is assembled first. Figure 23 is a top view of the receiver substrate assembly. The substrate is placed on a hot stage and the FORIC LCC is placed in the correct location on the substrate. Three capacitors are solder reflowed into their positions. Additional solder is added to the base of the terminals to ensure that they are soldered to the substrate. The substrate is then removed from the hot stage. Two small Kovar tabs are soldered to the substrate with a pencil soldering iron. A shorting wire is soldered to the top of the LCC and to the ground terminal. The backside of the receiver substrate is shown in Figure 24. The back side metallization can be seen along with the heads of the staked terminals. The back side of the substrate is assembled by soldering the capacitor components in their correct position. A short gold Kovar tab is also soldered to the substrate. This tab will provide a shorting path between the substrate ground and the case of the housing.

PHOTODIODE ASSEMBLY

The photodiode component is epoxied to a retaining plate using a holding and alignment fixture. The fixture controls the centering of the photodiode and the distance from the face of the photodiode lens to



Figure 22
End View of Transmitter Module

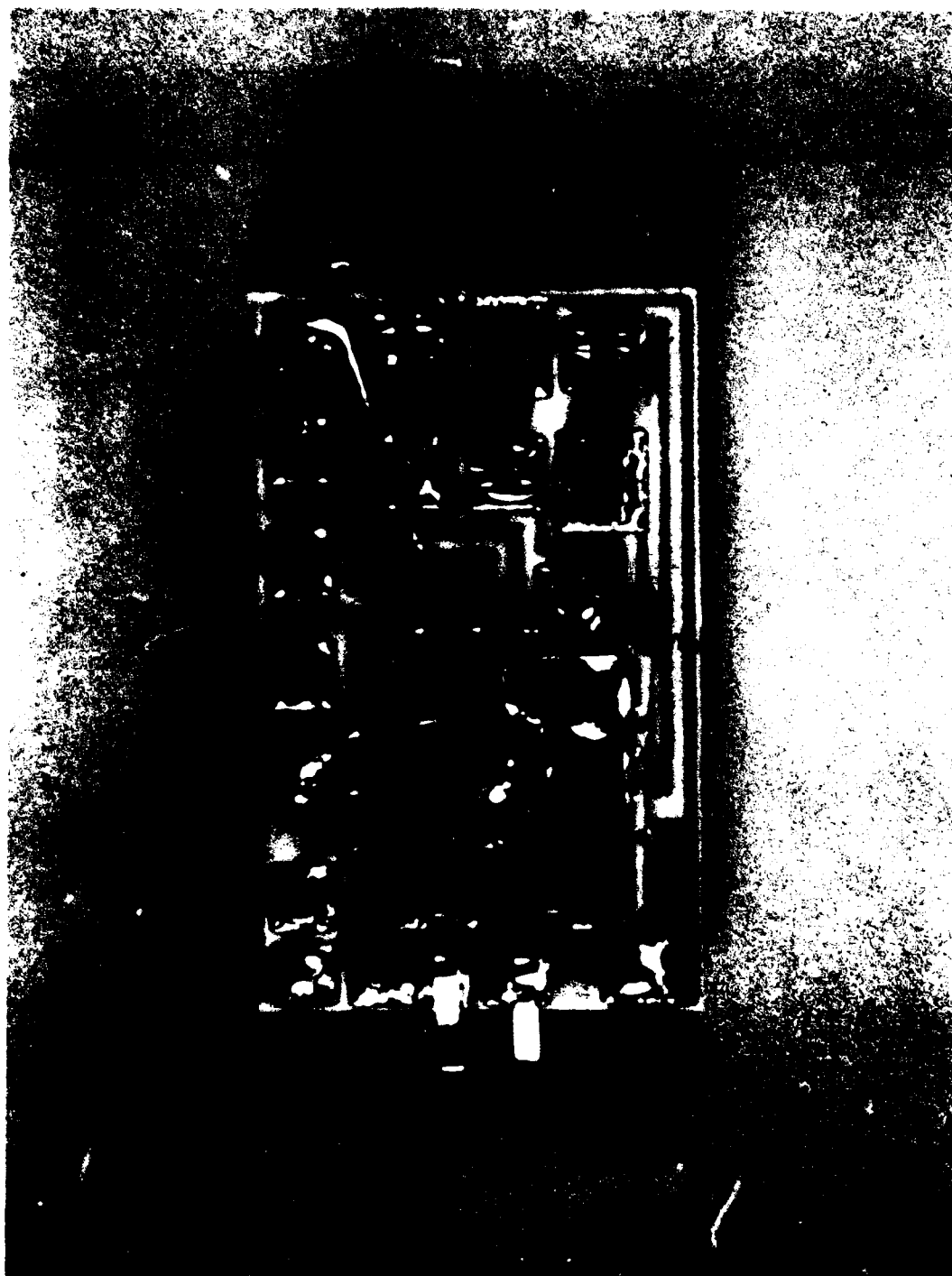


Figure 23
Front of Receiver Substrate

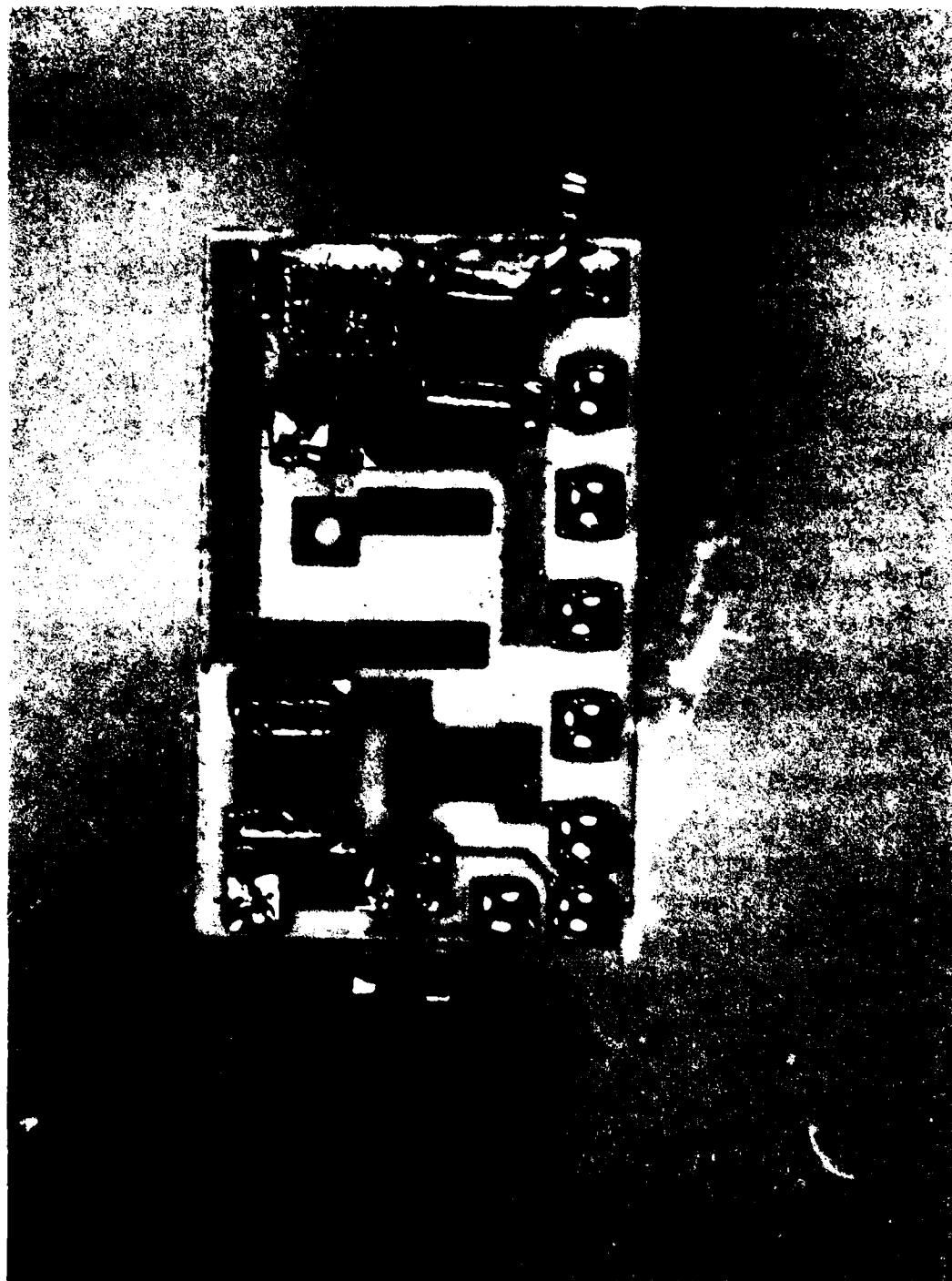


Figure 24
Back of Receiver Substrate

the back of the retaining plate to within $\pm .9$ mil tolerance. The anode and cathode terminals are clipped off .050 inch from the plate as shown in Figure 25.

RECEIVER SUBASSEMBLY

The short gold Kovar tabs of the receiver substrate assembly are then welded to the photodiode leads as illustrated in Figure 26.

RECEIVER HOUSING ASSEMBLY

The receiver subassembly is pushed into the guides of the extruded aluminum housing. Thermal epoxy is used between the substrate sides and the housing. The ground is connected to the housing by using conductive epoxy between the gold Kovar tab and the end plate. The module assembly is completed by attaching the optical connector and end plate to the housing with three 2-56 screws.

COMPLETED MODULE ASSEMBLY

The transmitter module compared to a dime is shown in Figure 27.

RECEIVER DESIGN PROBLEM

The first receiver module assembly did not work as designed and required more than $2\mu\text{Watts}$ of optical power before it would operate correctly. The receiver module should operate correctly with only $.4\mu\text{Watt}$ optical power input.

The receiver module was analyzed. Because of the fast fall time of the output ($<1\text{nsec}$), the di/dt coupled through the ground lead inductance caused an inductive kick to be coupled through the receiver IC substrate to its sensitive input. This resulted in an extra voltage spike in the output. The solution to the problem was to add a large (low inductance) wire directly to the module case in parallel with the ground path on the ceramic substrate ground.

Also it was found that as the number of TTL loads was increased the time duration of the spike was increased. Thus the number of TTL loads should be reduced to 2 for the best possible receiver module sensitivity. Load capacitance should also be minimized.



Figure 25
Photodiode Assembly

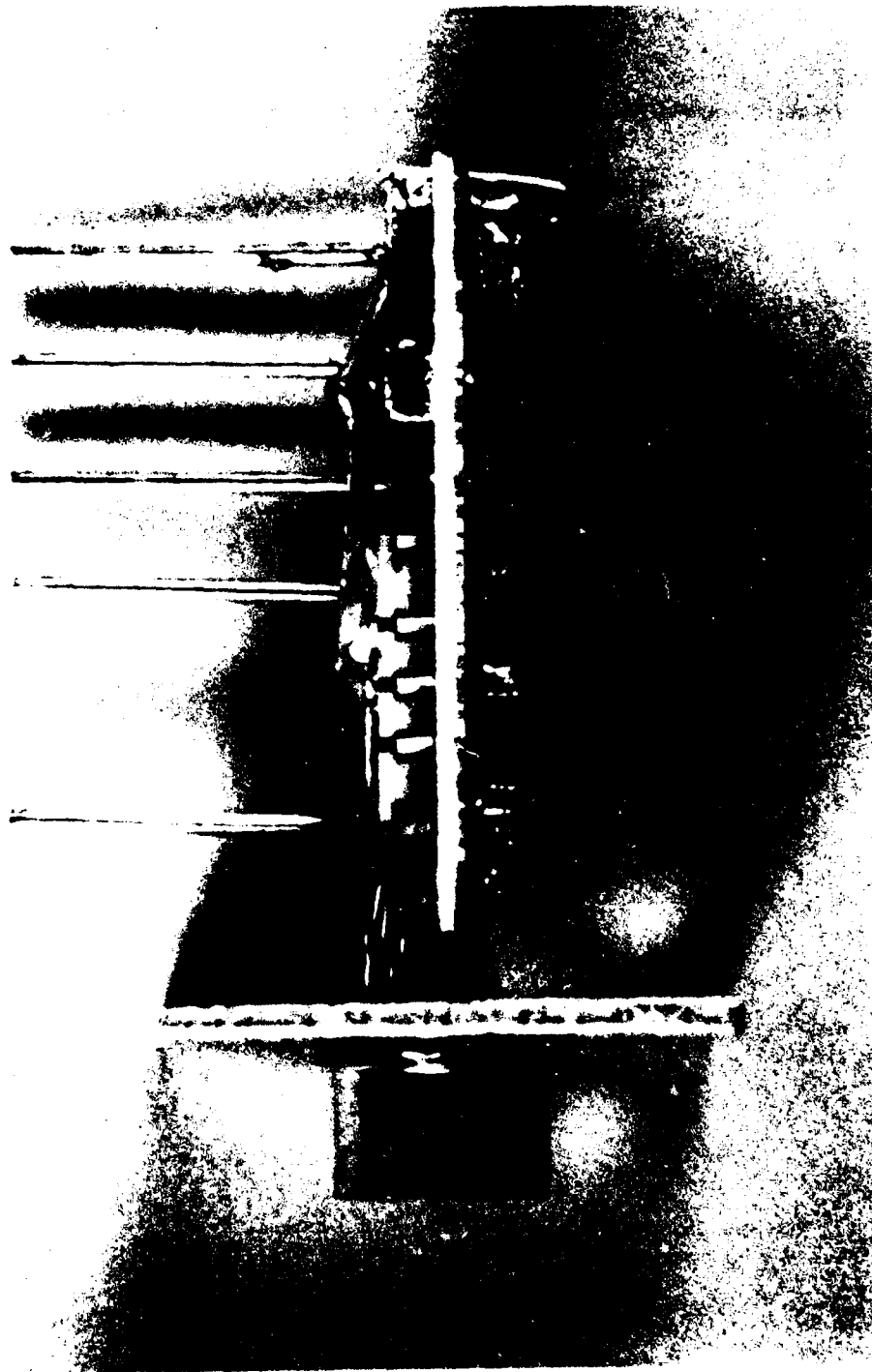


Figure 26
Receiver Subassembly

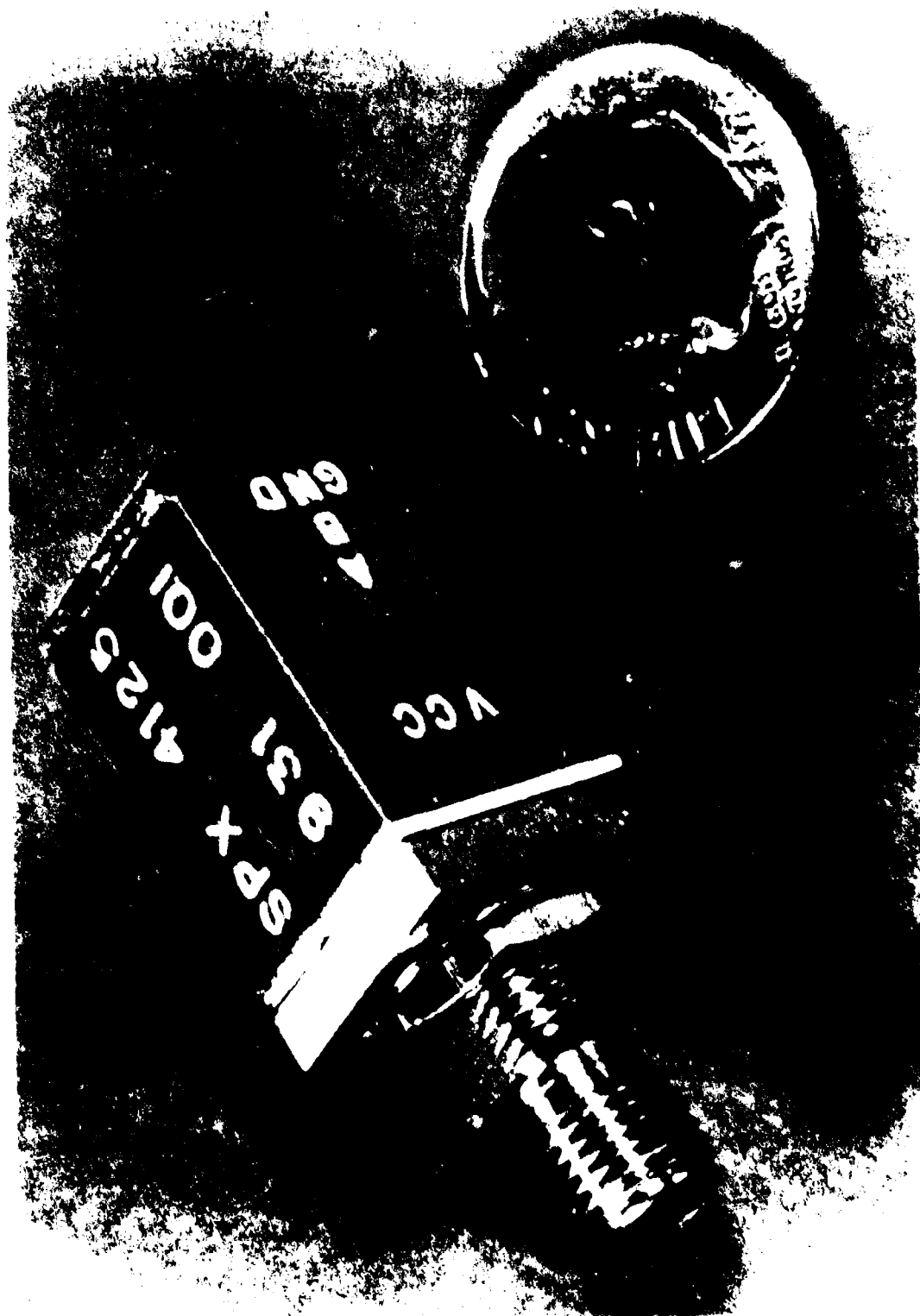


FIGURE 27
Completed Module

SECTION IX

FIBER OPTIC CABLE INTERFACE

The transmitter and receiver modules allow easy pluggable interface with almost any fiber optic cable provided it is terminated with the correct connector. Both terminated and unterminated Galileo 3000-19S fiber optic bundle cable was delivered as required by the contract. A termination kit was also specified and delivered.

CABLE CONNECTOR MATING REQUIREMENTS

The completed module is an all metal enclosure that allows easy interface with fiber optic cables. This is performed by the precision machined stainless steel optical connector on the front of the module. The optical connector will accept any Fiber Optic Cable terminated with a Spectronics optical connector or an Amphenol FOC series connector. The requirements of the cable connector in order to mate with the modules are shown in Figure 28.

TERMINATION KIT

The termination kit included instructions, a microscope, polishing tool, and enough connectors and supplies to perform 20 terminations. A picture of the termination kit is included as Figure 29.

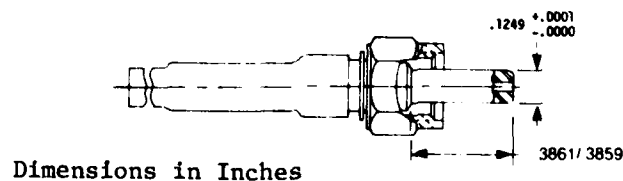


Figure 28
Fiber Cable Connector Mating Requirements

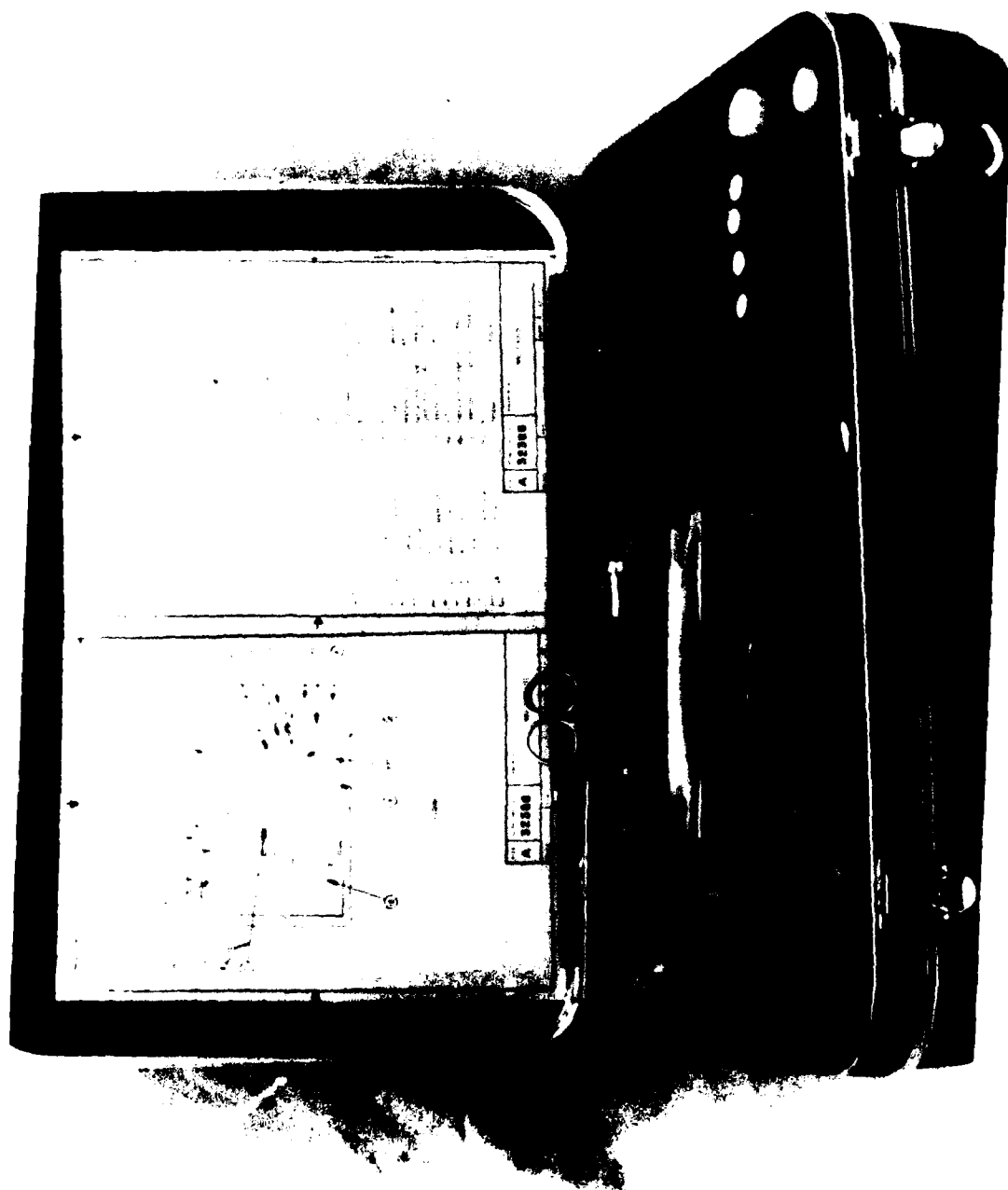


Figure 29
Fiber Optic Termination Kit

SECTION X

MODULE TEST PLAN AND RESULTS

TRANSMITTER MODULE TESTS

Table 12 lists the tests performed on the transmitter modules and the results.

STATIC TESTS

Table 13 lists the tests for the static test. The temperature condition specified is the worst case temperature for that test to meet MIL-R-5400 Class 2 equipment specifications.

Table 12
Transmitter Module Tests

TEST	DESCRIPTION	QTY STARTED	QTY PASSED
1	Static Test Per 3.1	63	61
2	Functional Test 1 Per 3.2	61	60
3	Optical Test 1	60	60
4	Burn-in for 168 hours at 125°C to MIL-STD-883 Condition B	60	
5	Functional Test I	60	60
6	Variable Frequency Vibra- tion per MIL-STD-750A method 2056, 30 G's	60	60
7	Temperature-Humidity- Altitude Test per MIL-STD- 810C, method 518.1	60	60
8	Functional Test II at -54°C, 23°C and at 95°C	60	60
9	Optical Test I at -54°C, 23°C and at 95°C	60	50
10	Optical Test II	50	50

Table 13
Static Tests

TEST No.	PIN TEST	1	2	3	4	TEMP. CONDITION	CONDITIONS	LIMITS		
								MIN.	MAX	UNITS
		Vcc	A	B	GND					
1.	LEAD TEMPERATURE						10 Sec.		260°C	
2.	MAX VOLTAGE	7.0V MC	.4	.4	GND	-65° to 150°C	NON OPERATING	10	50	mA
3.	MAX SUPPLY	5.5 MC	2.4	2.4		-54°C to +95°C	OPERATING		155	mA
4.	MAX INPUT VOLTAGE	5.5	5.5 MC	5.5 MC	GND	95°C			1	mA
5.	V _{IH}	5.5	2.4 MC	2.4	GND	95°C			40	mA
6.	V _{IH}	5.5	2.4	2.4 MC		95°C			40	mA
7.	V _{IL}	5.5	.4 MC	2.4		-54°C			-1.6	mA
8.	V _{IL}	5.5	2.4	.4 MC		-54°C			-1.6	mA
9.	INPUT CLAMP VOLTAGE	4.5	-12ma MV	-12ma MV		-54°C			-1.5	V

MC = Measure the Current
MV = Measure voltage with respect to ground

FUNCTIONAL TEST I

Functional Test I checks the switching characteristics of the module. These tests are listed in Table 14. A special test set-up was used to monitor the transmitter module RPO to check the switching characteristics. The set-up consists of a fiber optic bundle cable connected to the transmitter module on one end and pin photodiode on the other end, which drives a wide band preamp. The preamp output drives a wide bandwidth oscilloscope. The preamp is compared to the module input to test the module switching characteristics.

FUNCTIONAL TEST II

Functional Test II is the same as Functional Test I except it is performed at -54°C , 23°C , and 95°C .

OPTICAL TEST I

Optical Test I checks the RPO of the module. RPO is defined as the total radiant flux measured within an NA of .42 through the optical aperture of .045 inch diameter. The modules were tested by using a .045 inch diameter glass fiber calibrated for the effective NA of .42 and losses. The glass fiber was calibrated by measuring a known source with the glass fiber and calculating the calibration factor.

OPTICAL TEST II

The last test is Optical Test II in which the spectral range of the transmitter modules was measured. Figure 30 shows the typical spectral response for the 50 modules measured. The percent of the output falling in the specified range from 800 to 950 nm for the average module is approximately 86 percent.

RECEIVER MODULE TESTS

Table 15 lists the tests performed on the receiver modules and the results.

STATIC TEST

Table 16 lists the tests performed for the static tests of the receiver module. These tests check the performance of modules at maximum rating over temperature.

FUNCTIONAL TEST I

In this test, the receiver operating and switching characteristics were measured. The tests performed are shown in Table 17. These tests were

Table 14
Transmitter Module Switching Characteristics

PARAMETER	MIN	MAX	UNITS
Input Transition Time Low-to-High T_{ILH}	4	6	nsec
Input Transition Time High-Low T_{IHL}	4	6	nsec
Delay Time Low-to-High T_{DLH}		20	nsec
Delay Time High-to-Low T_{DHL}		20	nsec
Output Transition Time Low-to-High T_{OLH}		20	nsec
Output Transition Time High-to-Low T_{OHL}		20	nsec
Input Pulse Width T_1	40		nsec
Output Pulse Width T_3	$T_1 - 7$	$T_1 + 7$	nsec

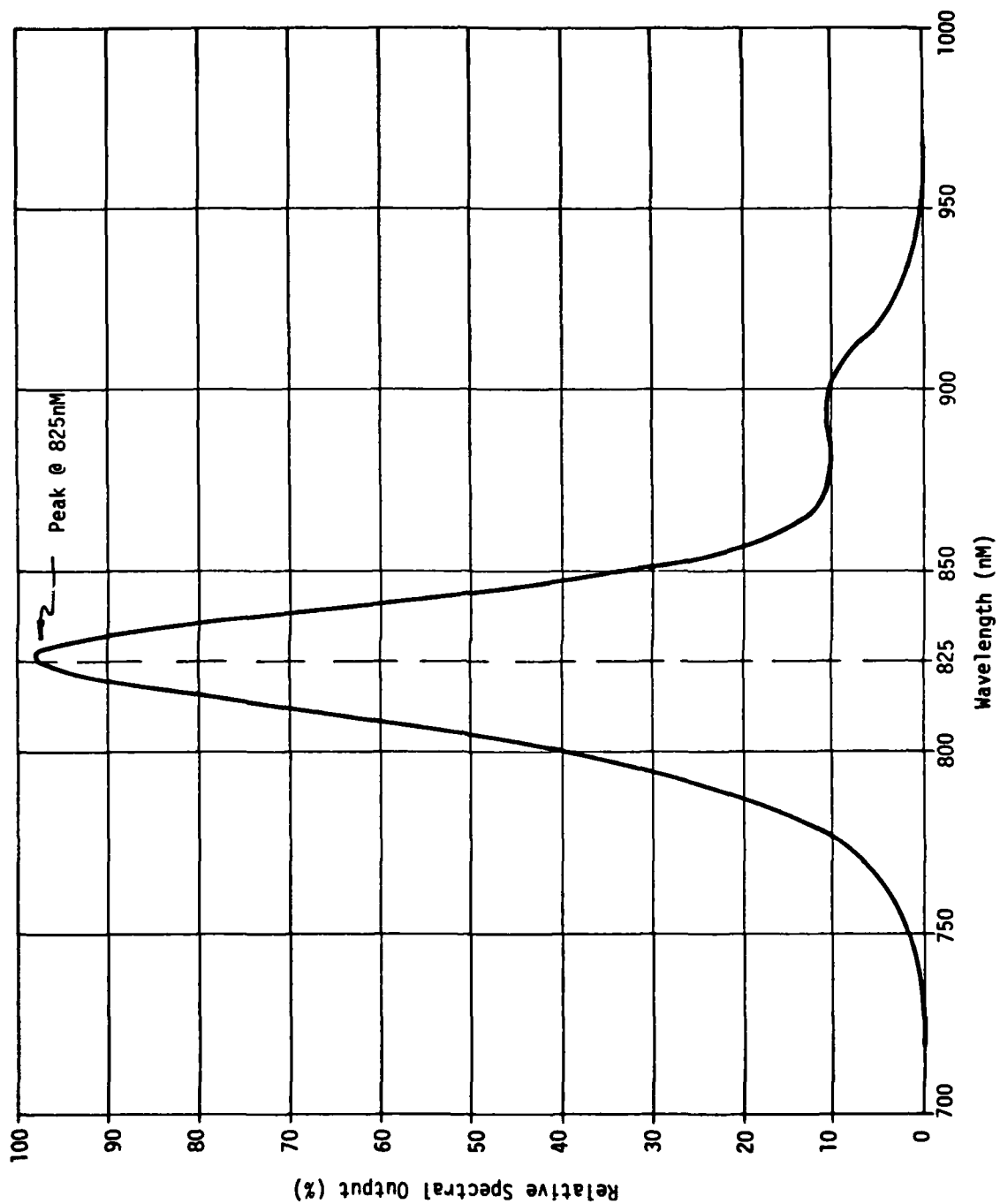


Figure 30
Typical Spectral Response

Table 15
Receiver Module Tests

TEST	DESCRIPTION	QTY STARTED	QTY PASSED
1	Static Tests	63	59
2	Functional Test I	59	53
3	Optical Test I	53	53
4	Burn-in for 168 hours at 125°C to MIL-STD-883 Condition B	53	-
5	Functional Test I	53	52
6	Variable Frequency Vibra- tion per MIL-STD-750A method 2056, 30 G's	52	52
7	Temperature-Humidity- Altitude Test per MIL-STD- 810C, method 518.1	52	52
8	Functional Test II at -54°C, 23°C and at +95°C	52	50
9	Optical Test I		
10	Optical Test II	50	50

Table 16
Receiver Module Static Tests

TEST No.	PIN	1	2	3	4	5	CONDITION	LIMITS		
								MIN	MAX	UNITS
1	Lead Soldering Temperature						10 Sec		260	°C
2	Max Supply Voltage (Non Operating)	90V	7.0V MC*		GND	GND	-65°C 150°C	10	70	mA
3	Max Supply Voltage (Operating)	90V	5.5V MC*		GND	GND	-54°C 95°C		55	mA
4	Output Short Current	90V	5.5V	GND MC*	GND	GND	-54°C 95°C		55	mA

*MC = Measure the current

Table 17
Receiver Switching Characteristics

PARAMETER	SYMBOL	MIN	TYP	MAX	UNITS	CONDITION*
Propagation delay time to high output level	t_{PLH}		65	75	ns	
Propagation delay time to low output level	t_{PHL}		60	75	ns	
Output Rise and Fall time (10% = 90%)	t_r, t_f			15	ns	
Bit Error Rate	BER			10^{-8}		$RPI \geq .4\mu W$

*All

$RPI > .4\mu W$

$C_L = 15pf$

$R_L = 390\Omega$

performed by using a calibrated light source connected by an 0.045 inch fiber bundle cable to an attenuator, which, in turn, was connected via another 0.045 inch diameter fiber bundle cable to the module optical input. The characteristics of set-up were known so that the module characteristics were determined by comparing the LED input of the test set-up to the receiver module output.

FUNCTIONAL TEST II

In Functional Test II, the tests listed in Table 17 were performed at -54°C , 23°C , and 95°C . During previous bit error rate (BER) measurements taken in Functional Test I, the pulse-jitter of the module was measured. If it was less than $2\mu\text{s}$, the BER was less than 10^{-8} .³ But for the final acceptance of the modules, the actual error bits were counted in Functional Test II.

The set-up to measure the BER included:

1. HP 3780A Pattern Generator/Error Detector
2. HP 216A Pulse Generator
3. NRZ to Manchester, Manchester to NRZ encoder and decoder circuit.

The Encoder and Decoder circuit is shown in Figure 31.

Using this circuit allowed the received pattern to be clocked at the center point in time of the received data Bit. The pulse width of the variable one-shot was adjusted until the rising edge of the \bar{Q} pulse of the one-shot was in the center of the received Manchester data and the D flip-flop detected the presence of the data. Using this simple scheme allowed for the individual time delays of each module tested.

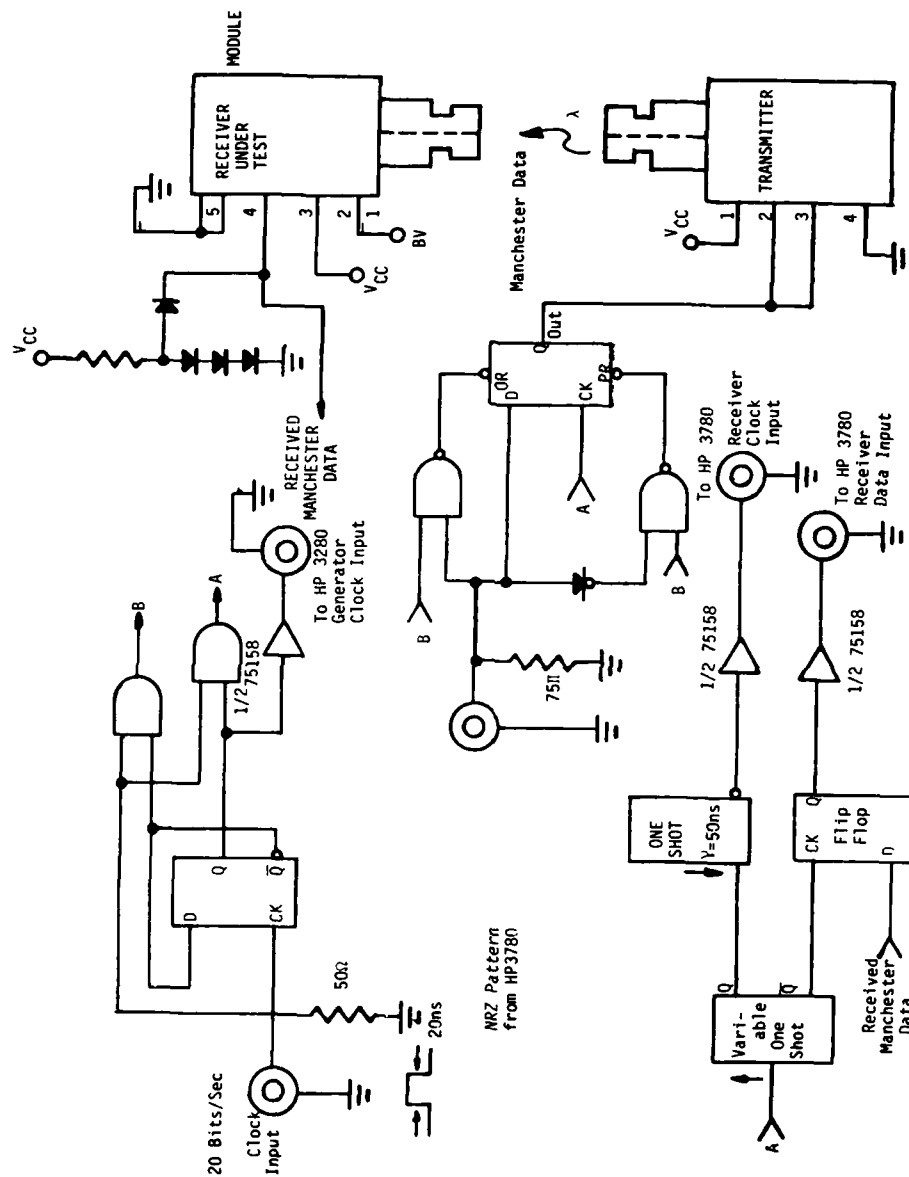


Figure 31
Encoder/Decoder Circuit

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